ESTCP
Cost and Performance Report

(UX-3002)

Evaluation of Footprint Reduction Methodology at the Cuny Table in the Former Badlands Bombing Range (2000 ESTCP Project)

January 2004

ENVIRONMENTAL SECURITY
TECHNOLOGY CERTIFICATION PROGRAM

U.S. Department of Defense

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **JAN 2004**	2. REPORT TYPE	3. DATES COVERED **00-00-2004 to 00-00-2004**
4. TITLE AND SUBTITLE **Evaluation of Footprint Reduction Methodology at the Cuny Table in the Former Badlands Bombing Range (2000 ESTCP Project)**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Environmental Security Technology Certification Program (ESTCP),4800 Mark Center Drive, Suite 17D08,Alexandria,VA,22350-3605**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**55**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

COST & PERFORMANCE REPORT
ESTCP Project: UX-3002

TABLE OF CONTENTS

Page

TABLE OF CONTENTS (continued)

LIST OF FIGURES

Page

LIST OF TABLES

ACRONYMS AND ABBREVIATIONS

AFB	Air Force Base
AGL	above ground level
BBR	Badlands Bombing Range
BRAC	base realignment and closure
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CTT	closed, transferred, and transferring
DoD	Department of Defense
DOE	Department of Energy
EE/CA	engineering evaluation/cost assessment
EMI	electromagnetic induction
EOD	explosive ordnance disposal
EPA	Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
FAA	Federal Aviation Administration
FAC	Federal Acquisition Cost
FN	false negative
FP	false positive
FUDS	formerly used defense sites
FY	fiscal year
GPS	global positioning system
ha	hectare(s)
HE	high explosive
HM3™	Helicopter-Mounted Magnetometer Mapping
IDA	Institute for Defense Analyses
ISMS	Integrated Safety Management System
m	meter(s)
MIPR	Military Interdepartmental Purchase Request
mm	millimeter(s)
m/s	meters per second
MTADS	Multisensor towed array detection system
nT	nanotesla
nT/m	nanotesla per meter

ACRONYMS AND ABBREVIATIONS (continued)

OE	ordnance and explosives
ORAGS	Oak Ridge Airborne Geophysics System
ORNL	Oak Ridge National Laboratory
PC	personal computer
P_d	probability of detection
QA	quality assurance
QC	quality control
ROC	receiver operating characteristic
STC	supplementary type certificate
USAESCH	U.S. Army Engineering and Support Center, Huntsville
UXO	unexploded ordnance

ACKNOWLEDGEMENTS

Utilization of Airborne Geophysics for the Detection, Characterization, and Identification of Unexploded Ordnance (UXO) at the Former Badlands Bombing Range, which documents the acquisition, processing, analysis, and interpretation of airborne remote sensing data for unexploded ordnance-related sites at the former Badlands Bombing Range, was prepared by the U.S. Army Corps of Engineers Engineering & Support Center, Huntsville (USAESCH), and the Department of Energy's (DOE) Oak Ridge National Laboratory (ORNL) under Military Interdepartmental Purchase Requests (MIPR) W31RYO90696 and W31RYO91270. This work was prepared through funding provided by the Environmental Security Technology Certification Program (ESTCP) Office and served, in part, to support engineering evaluation /cost assessment (EE/CA) activities at the former Badlands Bombing Range. The EE/CA work was known at the time of project planning and was particularly beneficial to the USAESCH. This project offered the opportunity to examine advanced airborne methods for their further applicability at Department of Defense (DoD) sites that contain unexploded ordnance and ordnance-related artifacts, such as waste burial sites, which present environmental and safety concerns for personnel.

We wish to express our sincere appreciation to Dr. Jeffrey Marqusee, Dr. Anne Andrews, Mr. Jeffrey Fairbanks, and Mr. Matthew Chambers of the ESTCP Office for providing support and funding for this project at the former Badlands Bombing Range. We also wish to thank Ms. Emma Featherman-Sam and the staff of the Badlands Bombing Range Project Office in Pine Ridge, South Dakota, for their invaluable support to the project planning, reconnaissance, and data acquisition phases of this project and Parsons Engineering Science for the ground follow-up, excavations, and EE/CA support.

Technical material contained in this report has been approved for public release.

This page left blank intentionally.

1.0 EXECUTIVE SUMMARY

1.1 BACKGROUND

As a result of past military training and weapons-testing activities, an estimated 12 million hectares (approximately 30 million acres) of U.S. land is potentially contaminated with unexploded ordnance (UXO) and/or weapons testing- and training-related artifacts. These contaminated areas include sites designated for base realignment and closure (BRAC) and formerly used defense sites (FUDS). Using current technologies, the costs associated with detection, identification, and mapping of this contamination has been estimated to be in the hundreds of millions of dollars. Current surface-based technologies have shown improvements in the ability to detect subsurface UXO but are unable to reliably discriminate UXO from other items that pose no risk. These approaches are generally labor intensive, slow, and expensive. Significant cost savings could be achieved if it is demonstrated that advanced airborne methods can provide a substitute for a portion of the surface-based applications. Typically, airborne magnetometers have not been used for UXO detection because of limitations in the physics and an inability to position the magnetic sensors in close proximity to the targets at or beneath the earth's surface. Recent demonstrations and advances in airborne magnetic systems have led to significantly improved performance over prior generation airborne systems. In addition to the aforementioned potential cost savings, an advanced airborne approach will also provide a safer operating environment for personnel performing UXO detection and mapping (stand-off versus direct ground contact), an ability to conduct surveys on difficult terrain or in locations not readily accessible from the surface, and a passive, nonintrusive approach by reducing or eliminating disturbance of indigenous plant and animal habitat.

The third generation airborne system utilized for this project was based on eight airborne-quality cesium vapor magnetometers mounted in three rigid 6-m booms (one forward, two lateral) that are mounted to the airframe of a commercial helicopter. Ancillary equipment included a laser altimeter and a real-time differentially corrected global positioning system (GPS) for navigation and data positioning. This configuration enabled operation at a nominal flight altitude of 1 to 3 m above ground level (AGL). The survey methodology consisted of parallel lines traversing the areas of interest with the survey lines adjacent to one another (as opposed to being interleaved as with the second generation system) so that eight traces of total magnetic field data were collected for each flight line providing a nominal data spacing of 1.75 m with a flight line spacing of 12 m. The survey process concludes with data processing, analysis, interpretation, and mapping using commercial software to generate digital images depicting locations and magnitudes of anomalies that may represent UXO.

1.2 OBJECTIVE OF THE DEMONSTRATION

The objective of the demonstration was to evaluate an improved airborne high-resolution magnetic system at selected sites at Badlands Bombing Range (BBR) for the detection and mapping of probable UXO-related contamination. This demonstration, in turn, was to be used to support the overall remediation of this site. This objective was based on validating detection and characterization of ordnance and ordnance-related debris at large previously unsurveyed areas and at a controlled test site using airborne magnetometer technology. Through the use of the airborne system on unknown sites and a known site, namely the thoroughly documented test site, this

demonstration survey produced results that confirm this improved technology is both practical and cost-effective for detection and mapping of UXO as well as wide-area surveillance associated with footprint reduction activities.

1.3 REGULATORY DRIVERS

No specific regulatory drivers influenced this technology demonstration. UXO-related activity is generally conducted under Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) authority. A draft Environmental Protection Agency (EPA) policy related to UXO is currently under review. Attempts to establish a "Range Rule" were abandoned in 2001. Regardless of a lack of specific regulatory drivers, many Department of Defense (DoD) sites and installations are aggressively pursuing innovative technologies to address a variety of issues associated with ordnance and ordnance-related artifacts (e.g., burial sites) that resulted from weapons testing or training activities. These issues include footprint reduction and site characterization, areas of particular focus for this technology demonstration. In many cases, the prevailing concerns at these sites become a focus for the application of innovative technologies in advance of anticipated future regulatory drivers and mandates.

1.4 DEMONSTRATION RESULTS

To validate the detection capabilities of the system, a controlled test site (Calibration Site) developed under a previous Environmental Security Technology Certification Program (ESTCP)-funded project was expanded and surveyed. Seeded items included engineering items, inert ordnance, and simulants that were selected to bracket the expected detection parameters of the system. The system succeeded in detecting all the seeded items, which ranged in size from 6 to 65 lbs at depths from 1 to 4.4 ft beneath the earth's surface. In addition to the Calibration Site, four additional known and unknown areas were surveyed totaling approximately 497 acres. The technology exceeded expectations and identified individual items. Of anomaly signals excavated, the percentage associated with intact ordnance or ordnance debris ranged from 48% to 97%, and the percentage that resulted in false positives ranged from 3% to 52%. Total project costs for all work performed by project team were $541,400 in FY 2000 dollars.

1.5 STAKEHOLDER/END-USER ISSUES

Issues related to this demonstration center on the appropriate use of the technology. Clearly, the improved airborne system is unable to detect all UXO items of potential interest, which is also true of known ground-based systems. The technology continues to be constrained by the presence of tall vegetation and severe terrain that increases the distance between the system and the UXO items of interest, thereby limiting detection ability. It remains apparent that application of the technology to small survey areas will not be cost-effective because of the high cost associated with mobilization and demobilization and considerable helicopter costs. Users should consider both the intended UXO targets and the size, terrain, and vegetation of the survey area before considering the use of airborne systems for UXO detection, mapping, or footprint reduction.

2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY DEVELOPMENT AND APPLICATION

Many methods have been proposed for the detection and identification of UXO. Surface and airborne measurements of the perturbations in the direction and strength of the earth's magnetic field can be used to locate underground ferromagnetic objects and structures. Although these methods have typically been used to characterize geologic features, they are also effective in locating ferrous man-made objects. While most methods require surface-deployed instrumentation (usually providing greater sensitivity), these methods generally have significantly higher acquisition costs (ranging from \$1,000 to \$4,000 per acre, depending on site conditions), are extremely time-consuming, and may present risks to personnel, equipment, and the environment.

With an estimated 12 million hectares (ha) (approximately 30 million acres) of U.S. land potentially contaminated with UXO or weapons testing-related artifacts, the costs associated with the detection, identification, and appropriate clean-up of this contamination could be several hundred billion dollars. Significant cost savings could be achieved if airborne methods could serve as a substitute for a portion of ground-based methods. Airborne magnetometers have not been used for UXO detection because of limitations in the physics and an inability to position the magnetic sensors in close proximity to the ground. Recent advances in airborne magnetic systems have demonstrated capabilities that approach those of surface-based systems.

Both total field and directional (e.g., vertical component) magnetometers can be deployed in fixed wing aircraft, but such a deployment cannot support the low altitudes and slow air speeds required for UXO-related applications. For helicopter surveys, the greatest sensitivity and shortest sample spacing are achieved with total field instruments employing optically pumped sensors, such as cesium vapor magnetometers.

Altitude, flight path spacing, sample interval along flight lines, background noise, and instrument noise levels determine the minimum target size that can be detected using airborne methods. UXO and UXO-related items at depths of several meters may be detected with airborne magnetic instruments. Surface magnetic measurements can be used in follow-up surveys to detect much smaller objects.

In the Oak Ridge Airborne Geophysics System (ORAGS)-Hammerhead used by this project (see Figure 1 and Figure 2), cesium vapor magnetometers are mounted at regularly spaced intervals in three rigid booms (one forward "hammerhead" 6 m boom, two lateral straight 6 m booms) mounted on the underside of the aircraft. This configuration enabled a nominal instrument altitude of 1 to 3 m AGL. Survey lines were directly adjacent to one another so that 8 traces of total magnetic field data were collected for each flight line, providing a nominal data profile spacing of 1.75 m with flight line spacing of 12 m. Noise effects were accommodated by using high sample rates with appropriate filters; close monitoring and compensation of the pitch, roll, yaw, and flight path of the helicopter; and by correcting the data on the basis of compensation measurements. These compensation measurements determine the effects of orientation when the helicopter is the only significant source

Figure 1. ORAGS-Hammerhead Airborne Magnetometer Platform at Badlands Bombing Range in South Dakota.

Figure 2. ORAGS-Hammerhead Airborne Magnetometer Platform at Shumaker Naval Ammunition Depot and Rocket Test Range in Arkansas.

of magnetic interference. The acquisition process concludes with real time signal processing to remove noise.

2.2 PROCESS DESCRIPTION

An operational summary is presented here with further detail provided in Sections 3 and 4. Mobilization is conducted by ground transportation of the electronic equipment and personnel. The helicopter and aircrew are mobilized by air to the base of operations. The base is usually a local or regional airport with suitable security and fuel. The geophysical base stations for GPS and magnetics are established at known civil survey monuments. A processing center is set up in a local hotel room.

Installation is conducted by the aircraft mechanic according to Federal Aviation Administration (FAA) requirements and the supplementary type certificate (STC) permit, with support of the geophysical ground crew. This involves dismounting the tow hook arrangement and installing brackets at these and other hard points in the airframe. The booms, sensors, and recording systems are subsequently attached to the bracket mounts.

Survey blocks are chosen and boundary coordinates determined. These are then entered into the onboard navigation system with consideration given to ambient magnetic fields, topography, vegetation, and survey efficiency. After installation, instruments are tested for functionality before and during an initial check flight. Calibration flights are then conducted to determine digital time lags and compensation coefficients required to correct the readings for the presence of the helicopter.

After calibration, site surveying commences. The pilot and equipment operator are present in the aircraft during survey operations. The operator is responsible for updating and managing the navigation software as well as real-time quality control (QC) of the incoming geophysical data. Surveying continues on a line-by-line basis until the entire block is covered. Depending on the size of the survey area, multiple flights may be required.

At the end of each flight, data are downloaded to a personal computer (PC) for QC evaluation. This includes verification of data integrity and quality from all sensor sources. Data from the ground base station instruments for differential GPS and magnetic diurnal adjustments are integrated with the airborne data. The dataset is analyzed for completeness of areal coverage (no large gaps or non-surveyed areas) and for consistency of survey altitude throughout the survey block. Lines or areas of unacceptable or missing data are noted and resurveyed as appropriate.

Upon completion of the survey, the data are processed to correct for the effects of digital time lag, selective availability in GPS, magnetic sensor dropouts, compensation for aerodynamic motion, magnetic diurnal, array balancing, regional magnetic field, helicopter rotor noise, and positioning of individual magnetometers. Magnetic anomalies are analyzed to derive dig lists and interpretive visual products (e.g., maps) depending on the application.

A variety of skilled personnel are required to conduct this type of geophysical survey. The pilot must be trained in low level or "ground effect" flying. The geophysical console operator must be skilled in making real time decisions regarding data quality in order to conduct immediate reflights.

The pilot must also be intimately familiar with the system in order to diagnose and effect any minor repairs in the field. The processing geophysicist must be familiar with airborne survey operation and data processing, in addition to analysis for UXO targets. All crew must be comfortable with safe operations in and around aircraft.

General and site-specific health and safety plans are generated for each survey project. Following the DOE Integrated Safety Management System (ISMS) process, these plans include provisions for general ground safety, extend them using DoD models for UXO site safety, further extend them to encompass airborne operations, then add wholly new considerations for airborne operations in a UXO theater. The appropriate management at Oak Ridge National Laboratory (ORNL), the helicopter operator, and the project sponsor approve these health and safety plans.

2.3 PREVIOUS TESTING OF THE TECHNOLOGY

This technology has evolved from traditional mineral exploration survey systems. While the fundamentals of magnetic surveying have not changed, the capabilities for mounting extremely high sensitivity magnetometers in such an inherently noisy platform were not successfully demonstrated until the mid-1990s. By 1997, the three-sensor Helicopter-Mounted Magnetometer Mapping (HM3™) system was the most technologically advanced system with noise reduction capabilities suitable for practical UXO detection.

In 1997, the HM3™ was tested at several different locations, including Canadian Forces Base Borden (Aerodat, Inc), Jüterbog Tank Training Range (IABG, GmbH) and Edwards Air Force Base (AFB) (ORNL). In a more recent 1999 application, the HM3™ was successfully used for an ESTCP demonstration at BBR. This demonstration involved surveys for a variety of ordnance and ordnance-related items at both known and unknown test sites and bombing targets.

2.4 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

The primary advantage of this system is that it can cover large areas of ground faster and cheaper than conventional ground-based surveys. Where large UXO items are involved, the wider sensor spacing and higher altitudes found in airborne arrays result in very little reduction in sensitivity. Detection of smaller items, however, is limited as a result of wider sensor spacing and higher altitudes. The airborne system also has an advantage in areas where ground access is limited or difficult due to surface conditions (swamp or marsh) or inherent danger (exposure to UXO or other contaminants). Areas with a sensitive ecological environment may also benefit from the less intrusive airborne technology.

At the time of this demonstration, no competing technologies to the ORAGS-Hammerhead were known to exist for airborne magnetic surveys, although several new platforms are proposed or are under construction.

3.0 DEMONSTRATION DESIGN

3.1 PERFORMANCE OBJECTIVES

Although airborne methods have historically been used to characterize geologic features, recent technological developments have led to an increase in sensitivity that makes these methods reasonable for detecting many types of UXO. The analysis of magnetic data for the project site areas focused on identifying the locations of surface and near surface UXO (and ordnance debris) and distinguishing between anomalies that occurred due to natural processes and those that resulted from human activities. Under the direction and guidance of U.S. Army Engineering and Support Center, Huntsville (USAESCH), ORNL and its team members acquired high-resolution magnetic data for identifying and mapping surface and near surface UXO and ordnance debris within the areas of interest at BBR. This data acquisition platform and the mission flights were characterized by innovative technical criteria, including an extremely low flight altitude, reduced flight line spacing, and higher data acquisition speed. GPS and altitude information were also acquired. The following summaries describe each sensor platform, performance parameters for each sensor, and the utility of each data type in identifying UXO and ordnance debris.

The system was designed for the detection of small amounts of man-made ferrous metal (potentially as small as 5 kg), but also to respond to larger man-made magnetic objects or naturally occurring rocks and soils that are magnetic. Simultaneously, real-time differential GPS data were acquired to geo-locate the magnetic data. The magnetometer system was mounted on a Bell 206L Long Ranger helicopter and flown at 1 to 3 m AGL. Flight line spacing was approximately 12 m with an aircraft speed of 60 mph. The design of the magnetic sensor array enabled simultaneous acquisition of data along eight lines. This unique acquisition procedure provided data at 1.75 m line spacing with measurements at intervals of 0.35 m along each line.

The objectives of this project centered on demonstrating the usefulness of the technology as a tool to aid in footprint reduction and to help delineate areas of concern for ordnance contamination. Sampling of anomalies of the appropriate sizes indicative of ordnance verifies the application. The technology exceeded expectations and successfully identified individual ordnance items including M38 practice bombs, 2.25-in and 2.75-in aerial gunnery rockets, and the locations and boundaries of aerial bombardment targets.

3.2 SELECTION OF TEST SITES

The former BBR, also known as the Pine Ridge Gunnery Range, is a formerly used defense site (FUDS) in the Pine Ridge Indian Reservation in Shannon and Jackson counties, South Dakota. Totaling more than 339,000 acres, portions of the site are flat and devoted to farming and ranching. The remaining acres are badlands, ranging from gently rolling to nearly vertical in topographic relief, that formed because of the extensive rapid erosion of the soft, fine-grained underlying sediments. The badlands are primarily devoted to grazing. A portion of the site is now part of the Badlands National Park.

With regard to historical ordnance, many areas across the site were used for aerial gunnery, aerial bombardment, and surface-based gunnery activity. Historical records indicate use of the range

began in the early 1940s and ended in the mid-1970s. Groups that used the range include Rapid City AFB (now Ellsworth AFB), the U.S. Army, and the South Dakota Army National Guard. Ordnance types found at the former BBR include 75 mm high explosive (HE) projectiles; 105 mm and 155 mm HE and illumination projectiles; 8-in HE projectiles; M38 practice bombs; M50 and M54 incendiary bombs; and 2.75-in and 2.25-in rockets.

This site was chosen for this technology demonstration because of favorable terrain and underlying geology, reasonable ordnance objectives (size, expected depth, composition, etc.), and the opportunity to integrate with ongoing engineering evaluation/cost assessment (EE/CA) activities being conducted by the U.S. Army Corps of Engineers (i.e., leverage of field resources). All these factors contributed to an increased likelihood of success.

3.3 TEST SITE HISTORY AND CHARACTERISTICS

The four sites selected for the survey are scattered throughout the Pine Ridge Indian Reservation in Sectors 2, 3, 4, and 7. The areas range from a few hundred acres to several thousand acres and have generally flat topography. Each area has been or is currently being used for farming and grazing of livestock. Each site is known to contain at least one aerial gunnery target or aerial bombardment target with an associated presence of ordnance and explosives. The purpose of the survey was to acquire, process, and analyze geophysical data for suspected subsurface ordnance items, ordnance-related artifacts, and buried waste sites. The survey areas are described below.

- Scenic/XU Hill Bombing Target (Figure 3) is an area in Sector 2 east of Cuny Table that is unfenced and easily accessible. This site does not contain a visible target. Very large impact craters are visible from the air and at the surface.
- White River Bombing Target (Figure 4) is an area in Sector 7 that is unfenced but not easily accessible by land. This site does not contain a visible target. Very large impact craters are visible from the air and at the surface.
- Target II East of Scenic on Bouquet Table, generally known as the Bouquet Table Target (Figure 5), is in Sector 4 east of Cuny Table. This site contains a large visible circular target. This target is extremely remote and difficult to access by surface transportation. M38 debris is readily visible at the surface.
- Target South of Radar Site, generally known as Radar Target (Figure 6), is an area in Sector 3 that is remote and difficult to access. This site contains a large circular target visible in both aerial imagery and at the surface. This site also contains scattered M38 debris across the target field.
- While not identified specifically as a target for the survey, the Calibration Site on Cuny Table was also used for this project. The Calibration Site, documented in previous reports, is a small, controlled test area with seeded items consisting of ordnance, ordnance-related items, and engineering items such as galvanized pipe and rebar. This area is located on the northern side of Cuny Table and is briefly described in Section 3.4.2.

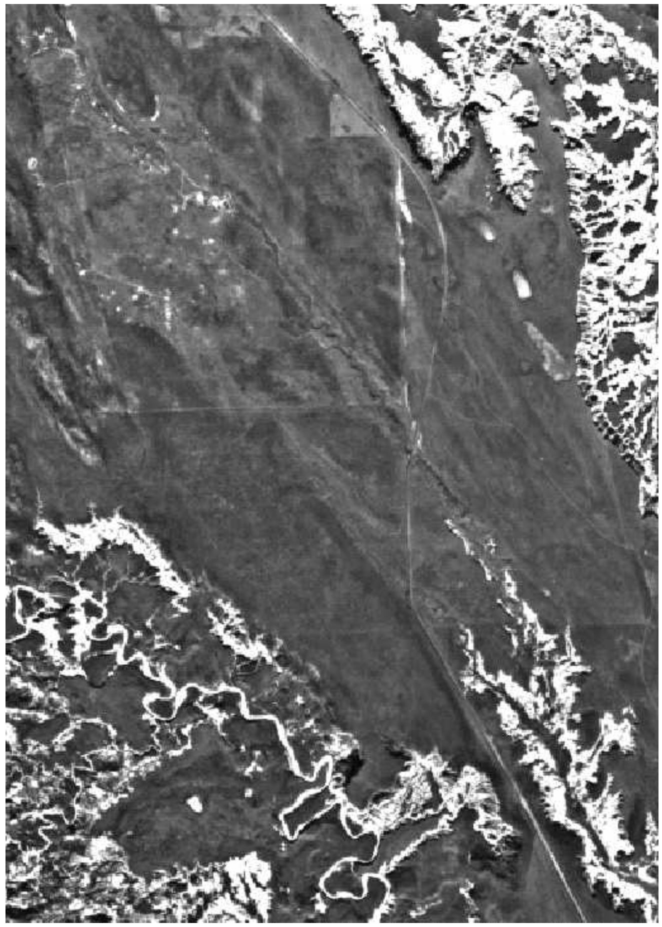

Figure 3. Aerial View of Scenic/XU Hill Bombing Target.

Figure 4. Aerial View of White River Bombing Target.

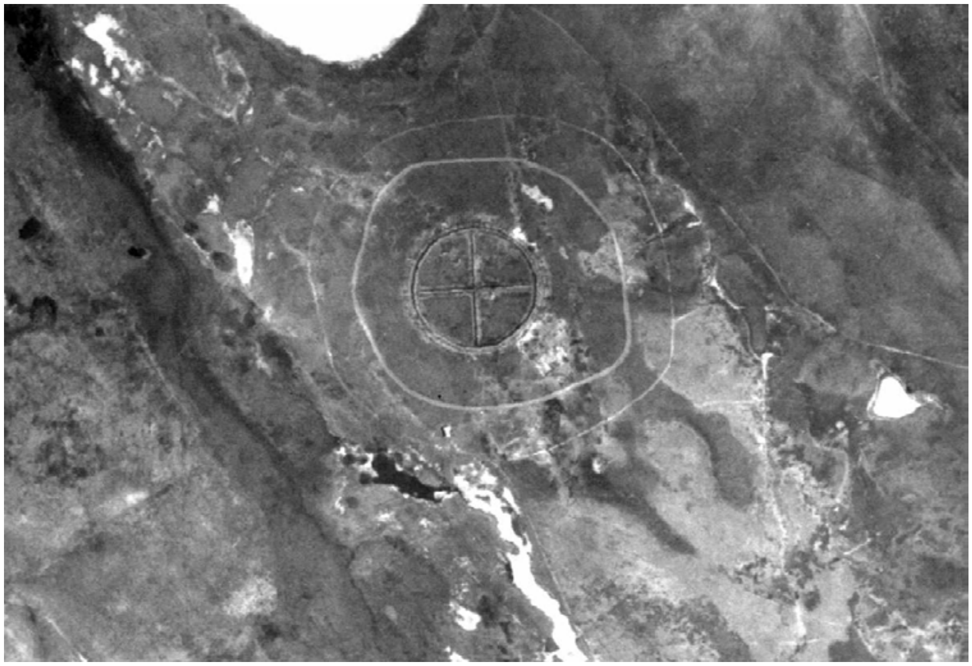

Figure 5. Aerial View of Target II East of Scenic on Bouquet Table.

Figure 6. Aerial View of Target South of Radar Site.

As mentioned previously, general topography across all survey areas was flat to gently rolling. Trees, buildings, power lines and other obstacles were rare, and were generally clustered together. Barbed wire livestock fences were the only real obstacles that were encountered during data collection.

In total, 179 line-km of data were collected from all eight sensors on the helicopter platform. The area surveyed was approximately 201 ha (497 acres). Data sample density on the ground was a function of the forward speed of the aircraft. Nominal spacing between lines was 1.75 m. At 60 Hz data recording rate and an average air speed of 25 meters per second (m/s) (approximately 60 mph), the spacing between sequential readings along a flight line was 0.35 m.

No cultural features (e.g., buildings, power transmission lines, etc.) were present at this site that in any way interfered with detection and mapping of the suspect UXO items. Overall, the geologic features of this site were considered benign and very conducive to the application of airborne-based geophysics.

3.4 PHYSICAL SET-UP AND OPERATION

3.4.1 Overall Survey

The survey was conducted September 17 to 26, 2000. Table 1 provides the respective parameters of the survey sites. Four survey missions were required to complete the entire project and each recorded data in digital files. Aircraft ground speed was maintained at approximately 25 m/s (60 mph) with a mean terrain clearance ranging from 1 to 3 m consistent with the safety of the aircraft and crew.

Table 1. Survey Sites' Geographic Descriptions.

Name	Coverage (in ha)	Coverage (in acres)	Line km
Scenic/XU Hill Bombing Target	72	178	44
White River Bombing Target	22	55	37
Bouquet Table Target	67	166	68
Radar Target	40	98	31
Calibration Site	1	2.5	3

The survey aircraft was a Bell 206L Long Ranger helicopter and operations were based out of Rapid City Regional Airport. The GPS and diurnal monitor base stations were established on Cuny Table near Site 1, the location of a known geodetic marker.

A comprehensive Operational Emergency Response Plan (Site-Specific Health and Safety Plan) was developed to address issues related to flight operations, safety, and emergency response. This plan was incorporated into an overall Mission Plan developed to manage field survey operations.

3.4.2 Calibration Test Site

During a previous ESTCP project, a controlled calibration test site was established and developed on Cuny Table to understand the limitations of the sensor technology, as well as signatures generated by each item suspected to exist with the former BBR. Targets were chosen to bracket expected detection parameters, and their locations were known to the investigators. The logistics associated with the site include:

- Establishing a survey grid 105 m in the north-south direction and 150 m in the east-west direction. Burial locations were staggered and placed at approximately 20 m linear spacing between locations.
- Establishing fiduciary data (dimensions, weights, and descriptions) on all items to be buried, including photographs prior to burial.
- A preseeding survey of the site using a Geometrics Model G-858 magnetic gradiometer to determine the background geology, soil conditions, and the presence/absence of any pre-existing ferrometallic "clutter."
- Excavating the burial sites using a commercial backhoe and subsequently burying the objects of interest in the ground. Fiduciary data were recorded for each buried item, including depth to the top of the item, burial orientation, azimuth, inclination, etc.
- A postseeding survey of the site, again using the Geometrics Model G-858 magnetic gradiometer, to determine ground-based geophysical signatures of each item for comparison to airborne geophysical data and for reacquisition of the items in the future.

3.4.3 Physical Set-Up of Airborne Technology

The ORAGS-Hammerhead system is arranged with sensors in each of three booms. The GPS antenna is mounted in the forward boom and the booms converged at the "hook." The distance between the GPS antenna and the forward sensor is 1.2 m, the distance from the GPS to the hook is 6.1 m, and the distance from the hook to the lateral sensors is 6.1 m. These numbers, plus the aircraft orientation, were required to calculate the position of each sensor.

The laser and radar altimeters were mounted beneath the helicopter at roughly the same altitude as the sensors themselves.

Data were recorded digitally by a new high-speed data acquisition system in a proprietary data format. All raw data were sampled at 1,200 Hz and downsampled to a 60 Hz sample rate. Data were imported into a Geosoft format database for processing. All data processing was conducted using the Geosoft software suite.

The sensors used were Cesium vapor optically pumped magnetometers with sensitivity of 0.001 nanotesla (nT). A global positioning system was operated in real time differential mode to control aircraft navigation. The receiver antenna was mounted on the forward boom while a second system acted as the base station.

During flight, magnetic data from the sensors were passed to the onboard console where the raw signal was processed into magnetic field strength. The data were filtered to remove high frequency

noise associated with the helicopter; time stamped for correlation to other data streams, and recorded. Data were transcribed into a database post flight where additional processing was conducted.

Because the earth's magnetic field is in a constant state of flux, a base station sensor was established to monitor and record this variation every few seconds. With normal variations, the recorded data were subtracted directly from the airborne data on a point-by-point basis. The time stamps on the airborne and ground units were synchronized to GPS time.

The ORAGS-Hammerhead system provides eight tracks of total field magnetics at low altitudes. The analytic signal was calculated from the final gridded total field data. There are several advantages to using the analytic signal. It is generally easier to interpret than total field data for small object detection. Total field measurements typically display a dipolar response to small, compact sources, i.e., they have a positive and negative component. The actual source location is at a point between the two peaks that is determined by magnetic latitude of the site and the properties of the source itself. Analytic signal is generally symmetric about the target, is always a positive value, and is independent of magnetic latitude. More generally, the analytic signal highlights the corners of source objects, but for small targets, these corners converge into a single peak.

Differential corrections to GPS information were completed in real time using a satellite link to a commercial base station network. If this link was broken, no differential corrections were made to the data and the raw GPS position was recorded. The status of this link was recorded in a separate data channel.

Data were examined in the field to ensure sufficient quality for final processing. The adequacy of the compensation data, heading corrections, time lag, orientation calibration, and data format compatibility were all confirmed during data processing. During survey operations, flight lines were plotted to verify full coverage of the area. Missing lines or areas where data were not captured were rejected and reacquired. Data were also examined for high noise levels, data dropouts, loss of real time differential correction or other unacceptable conditions.

3.5 SAMPLING PROCEDURES

None of the sites in this project had been previously mapped using ground-based technology. During this demonstration, a significant number of anomalies were excavated to validate performance.

All target anomalies acquired with the airborne system at the four sites were stored in a Geosoft database. Each line in the database represented the survey site with the corresponding number. Individual targets were sorted by amplitude and numbered for identification. All peaks over the background noise threshold of 0.5 nanotesla per meter (nT/m) were selected. Maps of the target locations were made by plotting colored symbols with ID numbers. The colors corresponded to those used in the analytic signal map.

No attempt was made to deselect anomalies. The purpose here was not to demonstrate the discrimination capabilities of the analytical tools but the detection capabilities of the airborne survey technology.

4.0 PERFORMANCE ASSESSMENT

4.1 CALIBRATION SITE PERFORMANCE

A controlled Calibration Site was established through a previous project on Cuny Table. At the conclusion of that project, several items were removed. This site was re-used for this demonstration; however, it was enlarged and additional ordnance items were emplaced. The tests at the Calibration Site demonstrate the detection limitations of the sensor technology and provide representative signatures generated by each item suspected to exist on the former BBR. Targets were chosen to bracket expected detection parameters and were known to the investigators. A target list is provided in Table 2, and residual magnetic and analytic signal results are presented in Figure 7 and Figure 8.

Background noise in the system averaged 0.5 nT/m in the analytic signal. All targets with a response of 0.55 nT/m or higher were detected by the airborne system. In total, 99 anomalies were picked from the analytic signal grid above 0.55 nT/m, of which 42 were seeded items. This produces a detection probability of 76% (42/55). This figure is anomalously low, as it includes the aluminum rods and other targets that were known to be too small for the system to detect but were included to "bracket" the threshold capabilities. Similarly, at this threshold setting, the false positive ratio is 57% (57/99). Again, it should be noted that the statistical significance of these numbers is limited by the small target count.

In general terms, all targets larger than the 81 mm mortar were detected reliably. This includes the 2.25-in rockets and larger items. Exceptions to this were some of the 105 mm rounds, which appeared very weak, and some of the 60 mm mortars, which appeared unusually strong. This is most probably attributable to the burial depth. The strong response from the 20 mm cluster was also unexpected. The aluminum rods were not expected to be detected but were emplaced for the concurrent testing of an airborne electromagnetic system.

If all the targets smaller than the 2.25-in rockets are removed from consideration (81 mm and below), the detection probability changes to 93% (43/46). At this level, the three undetectable targets were #7006 (105 mm at 0.74 m), #7010 (105 mm at 0.74 m) and #7030 (2.75-in nose cone at 0.91 m).

This calibration grid formed the basis for setting the minimum threshold response to 0.5 nT/m in the analytic signal. This setting was used for all subsequent picks on the four survey blocks.

Table 2. Seeded Target Items in Calibration Site.

(All targets above 0.55 nT/m were detected by the airborne system.)

Easting (in m)	Northing (in m)	Depth (in m)	ID #	Description	AS (in nT/m)
410869.9	136683.2	0.52	6601	2-in galvanized pipe EW + pin	11.70
410872.4	136693.1	0.61	6602	rebar x3	3.31
410877.5	136711.8	0.75	6603	2-in galvanized elbow	2.13
410885.0	136731.0	0.69	6604	steel channel	10.86
410888.7	136751.3	0.33	6605	2-in galvanized pipe w/cap EW	1.82
410892.8	136771.1	0.43	6606	2-in galvanized pipe w/flanges EW	3.02
410884.7	136679.4	0.46	6608	I-beam section EW	17.45
410893.9	136717.9	0.49	6610	rebar x4	93.44
410901.0	136738.0	0.69	6611	I-beam	4.08
410910.0	136774.1	0.13	6613	100-lb bomb fragment	67.56
410901.0	136685.5	0.43	6614	100-lb bomb fragment	5.38
410907.0	136703.2	1.44	6615	250-lb simulant NS	39.04
410912.2	136723.9	0.79	6616	250-lb simulant EW	59.81
410916.3	136742.7	1.02	6617	100-lb intact bomb NS	10.51
410922.3	136761.4	0.43	6618	100-lb bomb fragment NS	6.02
410923.8	136770.3	0.49	6619	2.75-in rocket nose EW	0.68
410914.3	136671.7	0.13	6620	100-lb bomb fragment + corner pin	14.34
410918.4	136690.5	0.13	6621	100-lb bomb fragment	21.06
410922.5	136710.3	0.66	6622	2.75-in rocket body EW	0.59
410939.0	136767.0	0.43	6625	2.75 sim x2 NS/EW + pin	3.83
410904.6	136819.2	0.97	7001	stove pipe EW	25.45
410901.0	136798.0	0.61	7002	box beam EW	31.43
410902.9	136757.7	0.99	7003	250-lb bomb V	75.70
410937.0	136819.0	0.66	7004	105 mm V	3.14
410933.0	136801.0	0.69	7005	155 mm V	21.49
410947.5	136807.2	0.74	7006	105 mm NS	0.42
410942.5	136788.0	0.36	7007	61 mm V	0.57
410934.0	136749.0	0.79	7008	105 mm V	6.60
410926.8	136730.2	0.61	7009	2.75-in rocket NS	0.56
410965.4	136812.4	0.74	7010	105 mm EW	0.23
410954.5	136774.1	0.79	7011	81 mm NS	0.54
410948.4	136755.0	0.33	7012	81 mm NS	0.30
410943.4	136736.6	0.81	7013	Aluminum rods EW	0.28
410939.0	136717.3	0.48	7014	Aluminum rods EW	0.38
410933.8	136698.3	0.30	7015	Aluminum rods EW	0.29
410928.7	136677.5	0.43	7016	81 mm V	0.29
410981.0	136798.0	0.00	7017	coiled wire	2.20
410974.0	136777.0	0.08	7018	60 mm illumination round V	1.66
410968.0	136758.0	0.13	7019	60 mm illumination round NS	1.09
410961.7	136741.5	0.13	7020	60 mm illumination round EW	0.36
410956.2	136721.8	0.00	7021	20 mm scatter	0.72
410946.3	136683.6	0.56	7022	81 mm NS	0.17
410995.7	136791.9	0.61	7023	steel pipe EW	27.82
410983.0	136763.0	0.53	7024	2.25-in rocket NS	10.34
410978.9	136747.0	0.41	7025	60 mm V	0.15
410991.0	136734.0	0.56	7026	155 mm V	14.11
410985.8	136714.9	0.74	7027	155 mm NS	2.87
410981.4	136695.8	0.86	7028	155 mm EW	1.61
410964.0	136689.0	0.51	7029	100-lb bomb V	14.09
410976.1	136676.1	0.91	7030	2.75-in rocket nose NS	0.25
410959.1	136671.0	0.48	7031	81 mm EW	0.22
410869.8	136684.2	0.10	7032	grid 0,0	7.80
410909.0	136828.0	0.10	7033	grid 0,150	24.31
411010.0	136800.0	0.10	7034	grid 105,150	21.36
410971.4	136657.3	0.10	7035	grid 105,0	1.18

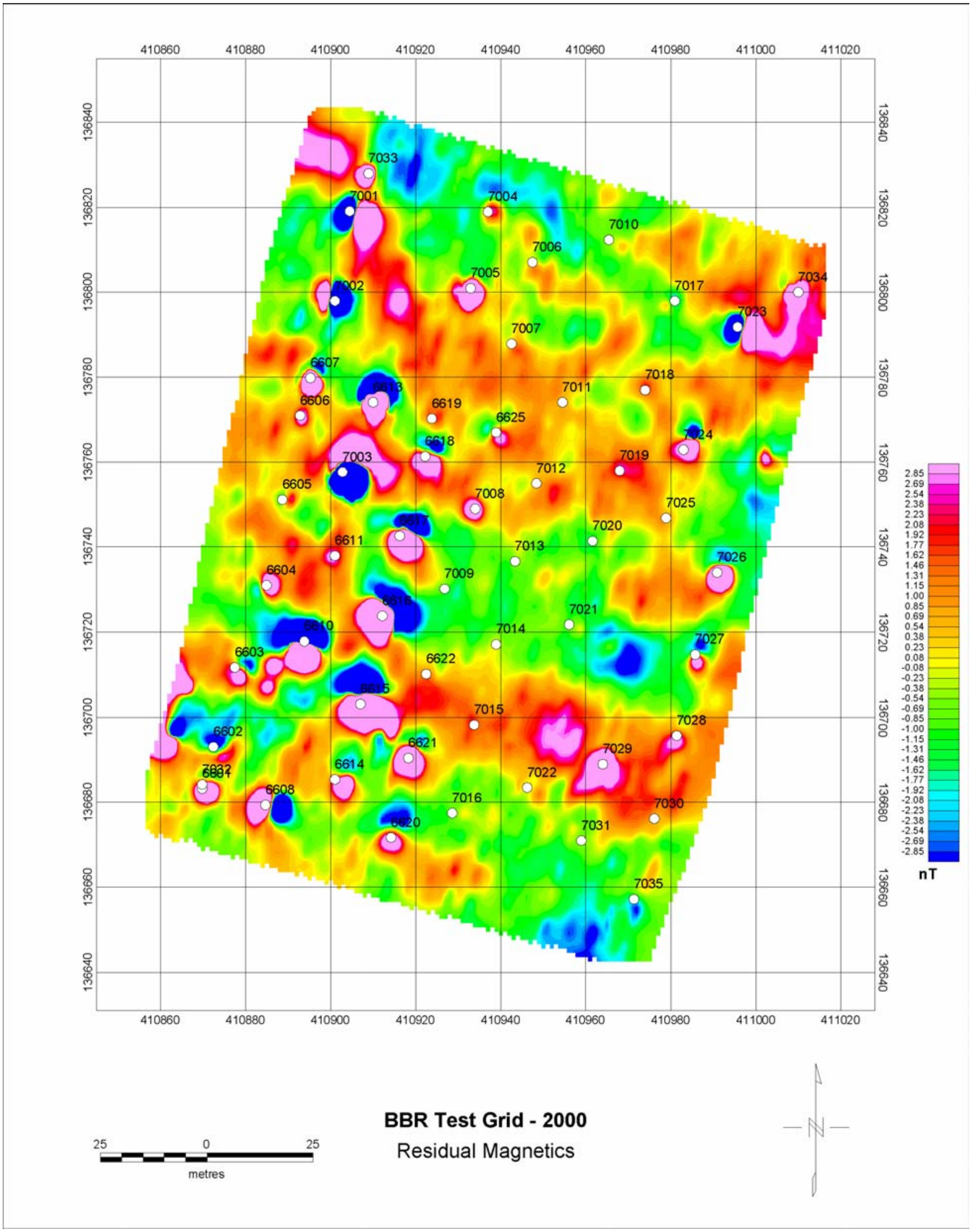

Figure 7. Residual Magnetic Field over the Calibration Site, with Emplaced Targets.

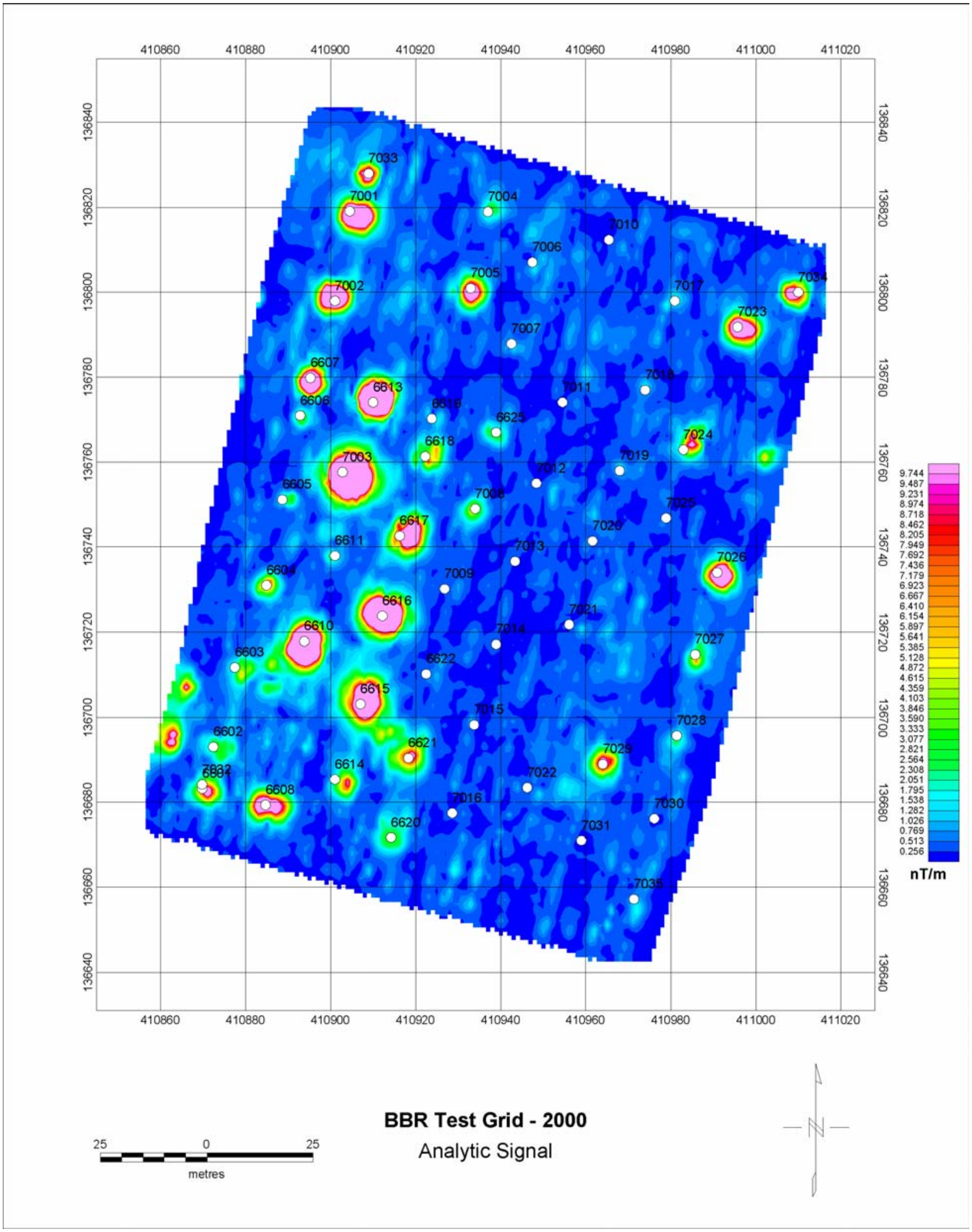

Figure 8. Analytic Signal over the Calibration Site, with Emplaced Targets.

4.2 SURVEY GRID RESULTS

Four project grids were surveyed as part of the ESTCP demonstration program. These included known bombing targets at Bouquet Table, Scenic/XU Hill, Radar Site, and White River. Survey logistics were presented in previous sections. Figure 9 through Figure 16 illustrate the residual magnetic field and analytic signal results from each of the four survey grids.

Anomaly peaks were picked from the gridded analytic signal down to the 0.5 nT/m threshold established in the calibration grid. Budget constraints limited the number of excavations possible, and previous experience dictated that there would be a significant reduction in successful excavations as the signal-to-noise decreased. The smallest response to an M38 or M38 frag in the calibration grid was 6 nT/m. It was therefore determined that a cutoff of 3 nT/m represented a reasonable threshold for detection of most M38s, while limiting the overall number of excavations.

Parsons Engineering Science, Inc. of Denver, Colorado, conducted ground follow-up on all four sites. The ordnance and explosives (OE) crew was given anomaly locations and magnetic signature strengths. All targets were found within 3 m of the specified coordinate. A consistent discrepancy was detected between the airborne and ground survey locations, presumably due to differing GPS base station locations. Once this effect was removed, targets were generally within 1 m of the assigned coordinate. Overall positional accuracy was slightly degraded from the previous deployment due to the use of satellite differential rather than local radio-link differential corrections. Post-mission differential corrections in future operations will provide an improvement over both of these real-time methods.

No discrimination was attempted on the anomalies other than amplitude thresholding. On all four grids, all anomalies greater than 3 nT/m were excavated and reported. For the purposes of calculating statistics, therefore, any metallic source, whether ordnance or scrap, was considered a successful detection. False positives were assigned when ground crews found either magnetic soils or no response. This would be consistent with the use of this technology as a footprint reduction tool and is consistent with the analysis of previous versions of this technology. Where reacquisition efforts found no response with handheld instruments, no hole was dug. The percentage figures used here are based on the number of excavations completed rather than the number of opportunities for detection. As a result, they should not be confused with probability of detection (Pd). A summary of the reacquisition results is presented in Table 3.

Scenic/XU Hill Bombing Target contained 221 anomalies with airborne responses ranging from 0.5-40 nT/m. Of these, 59 sites were investigated (representing all anomalies greater than 3 nT/m). Results yielded 19 M38 practice bombs, 1 50-caliber round and 9 OE frag. The remaining sites yielded 28 pieces of cultural scrap, and 2 no-contacts (3% FP).

White River Bombing Target contained 417 anomalies with airborne responses ranging from 0.5-42 nT/m. Of these, 31 dig sites were investigated. Results yielded 12 M38 practice bombs, and 6 pieces of OE fragments. The other sites yielded 8 pieces of scrap, 3 areas of "active" soils, and 2 no-contacts (16% FP).

Bouquet Table Target contained 1,042 anomalies with airborne responses ranging from 0.5-208 nT/m. Of these, 255 dig sites were investigated. Results yielded 122 M38 practice bombs, and 8 pieces of OE fragments. Other sites yielded 125 pieces of scrap and 0 no-contacts (0% FP).

Table 3. Ground Follow-Up from 2000 Showing 3% False Positive Responses After Excavating All Responses Greater Than 3 nT/m.

Area	Acres	Number of anomalies	Anomalies per acre	Maximum peak	Number of digs	Number of OE+OE fragments	Number of scrap	Number of "active" soils and/or no contact
Scenic/XU Hill	178	221	1.2	40	59	29	28	2
Radar	98	378	3.9	16	48	37	8	3
Bouquet Table	166	1,042	6.3	208	255	130	125	0
White River	55	417	7.6	42	31	18	8	5
TOTAL	**497**	**2,058**	**4.1**	**208**	**393**	**214**	**169**	**10**

Radar Target contained 378 anomalies with airborne responses ranging from 0.5-16 nT/m. Of these, 48 dig sites were investigated. Results yielded 35 M38 practice bombs, and 2 pieces of OE fragments. Other sites yielded 8 pieces of scrap, 2 "active" soil responses, and 1 no-contact (6% FP).

In total, the project detected 2,058 anomalies greater than 0.5 nT/m, of which 393 (19%) were greater than 3 nT/m and were followed up on the ground. Excavations produced 214 pieces of OE and OE fragments, 169 pieces of other scrap (97%), and 10 dry holes (3%). For the stated objective of proving magnetic detection capabilities, the system has performed better than the previous version (1999) that demonstrated a 90% detection rate with 10% false positives (see Table 4). The small number of excavations, particularly in 1999, limits the statistical relevance of a quantitative comparison of the o systems. Further, direct comparison of the 2 years' data sets is tenuous due to the differences in the selection processes used in each year.

Table 4. Ground Follow-Up from 1999 Showing 10% False Positive Responses After Excavating Selected Responses Greater Than 1 nT/m.

(The incidence of scrap is significantly lower in these areas due to continuous farming.)

Area	Acres	Number of anomalies	Anomalie s per acre	Maximum peak	Number of digs	Number of OE + OE fragments	Number of scrap	Number of "active" soils and/or no contact
Cuny Table Target (1)	92	49	0.5	17	17	13	1	3
Aerial Gunnery Target (2)	92	33	0.4	35	24	21	3	0
Burial Pits (4)	30	11	0.4	304	11	5	1	5
Stronghold Table Target (5)	42	117	2.8	163	30	28	2	0
TOTAL	**256**	**210**	**0.8**	**304**	**82**	**67**	**7**	**8**

Similarly, an analysis of the number of scrap items located within each area has little significance due to the nature and extent of scrap in each location and historic land use. Without the intention of discriminating between magnetic sources, even comparison between areas in a single year is difficult because of the differing nature and extent of scrap in each location. Without a complete excavation of the site to determine the number of opportunities for detection, the calculation of P_d is not possible. No additional anomalies (detected by other search technologies) were investigated for comparison. The only conclusion that can be reached by comparing these results to previous system results is that the number of false anomalies generated by the acquisition system was lower in 2000.

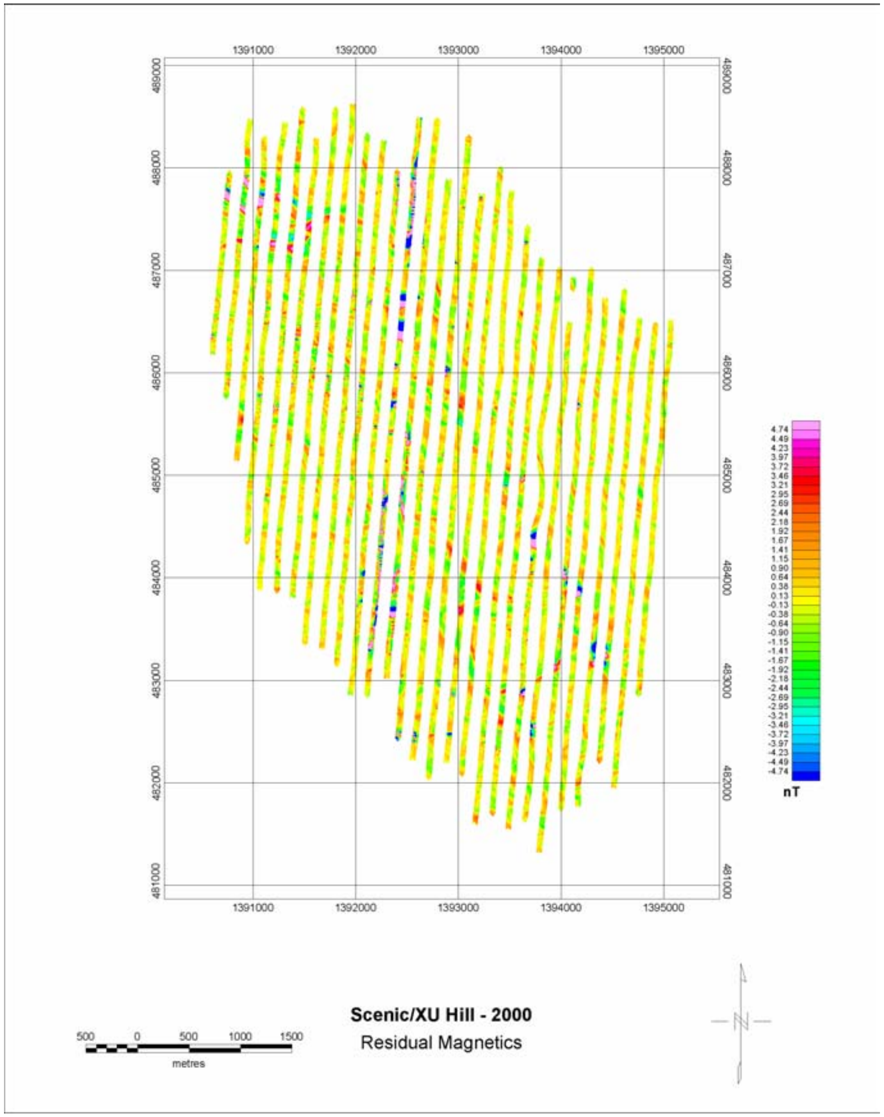

Figure 9. Residual Magnetic Field at Scenic/XU Hill.

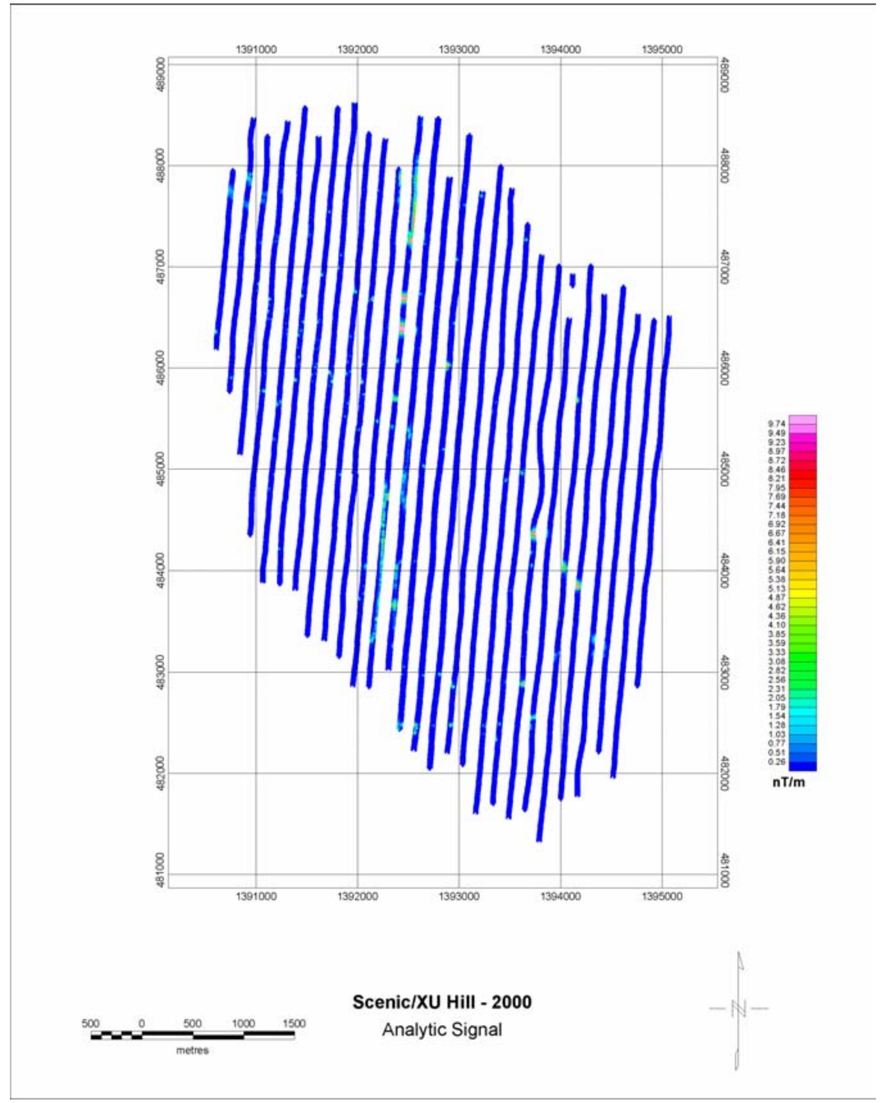

Figure 10. Analytic Signal at Scenic/XU Hill.

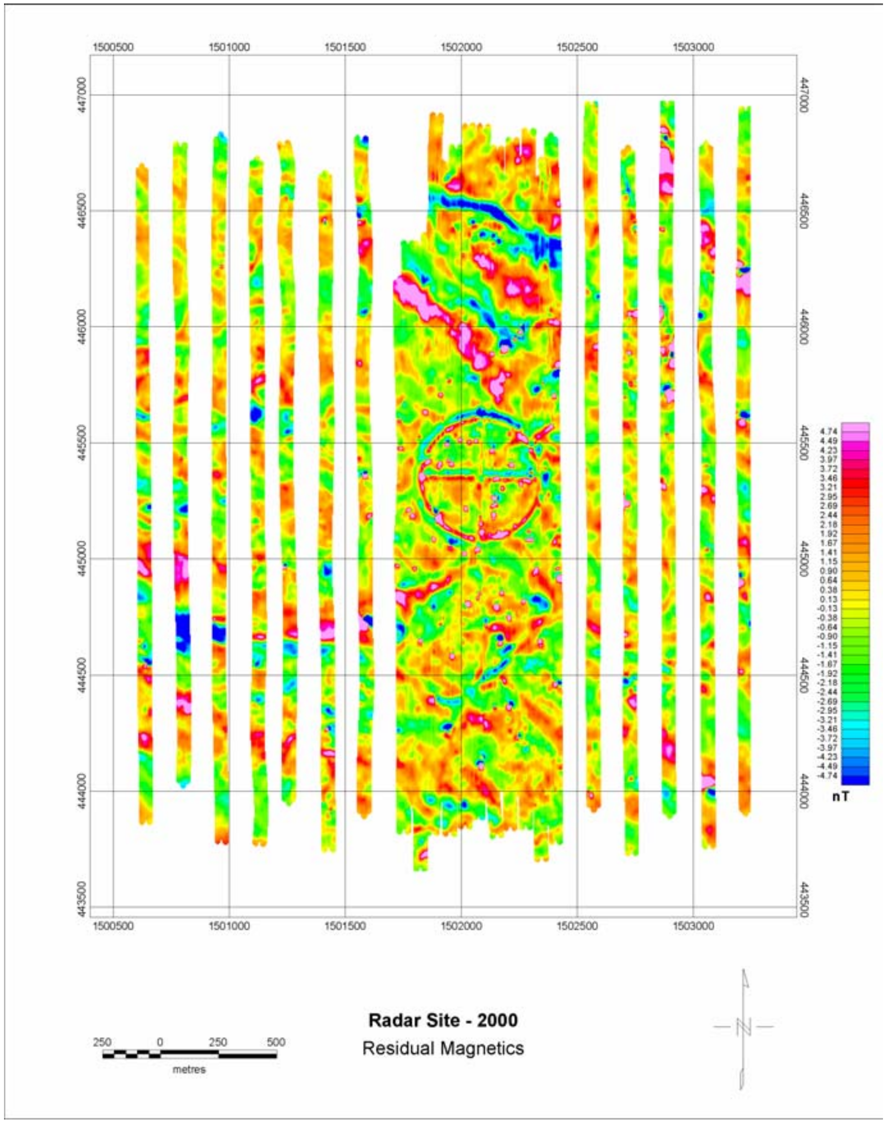

Figure 11. Residual Magnetic Field at Radar Site.

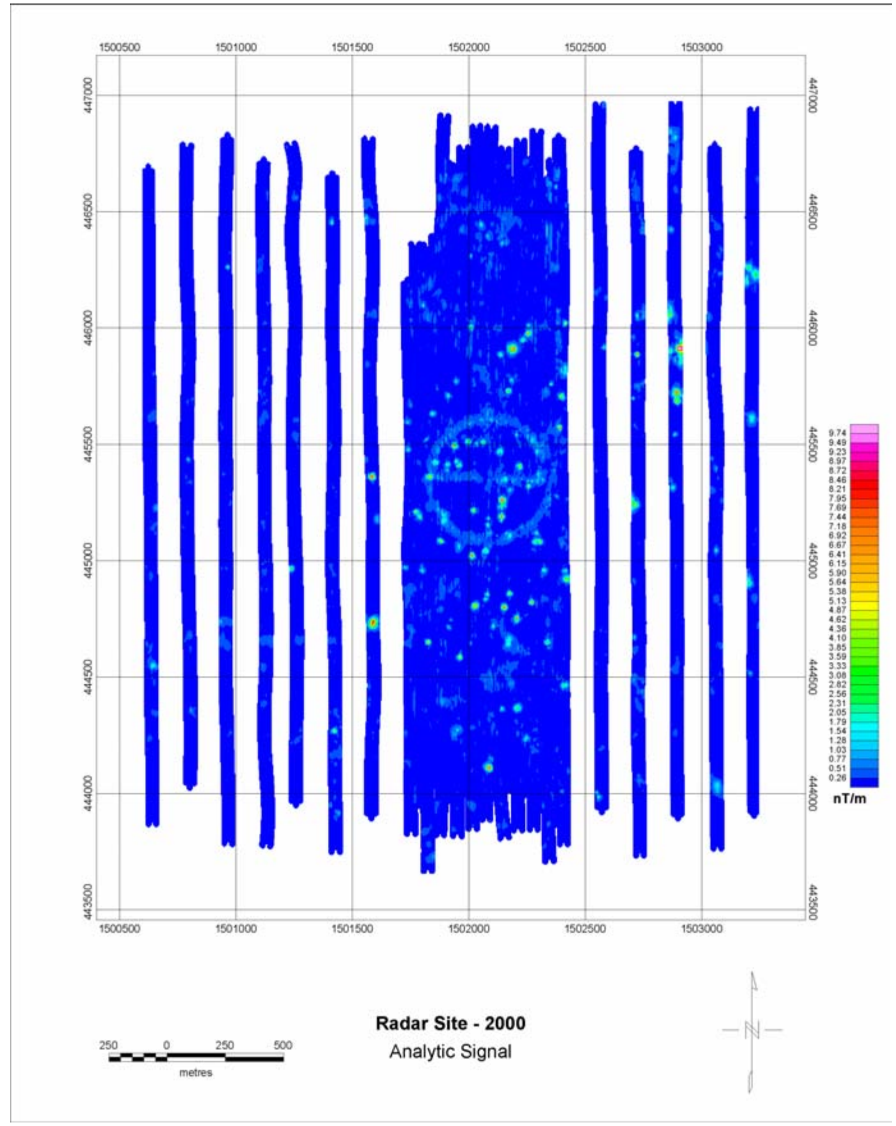

Figure 12. Analytical Signal at Radar Site.

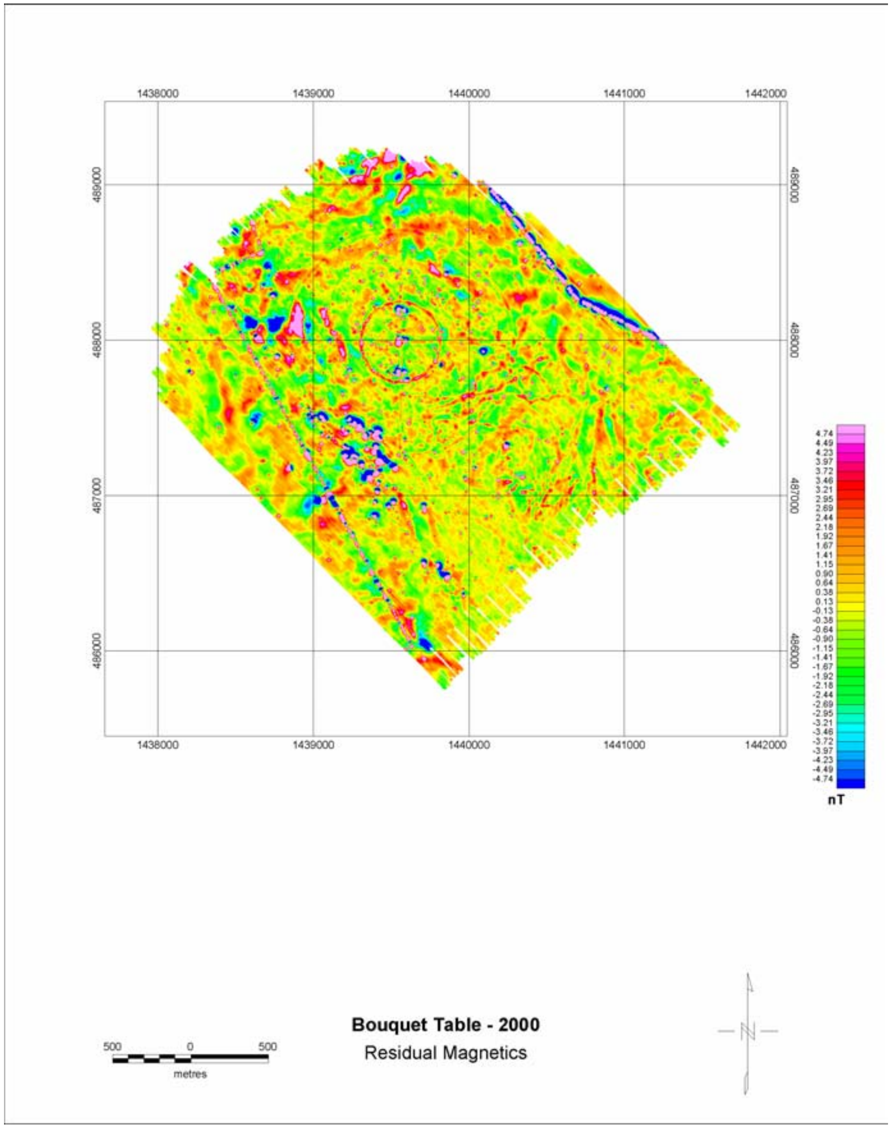

Figure 13. Residual Magnetic Field at Bouquet Table.

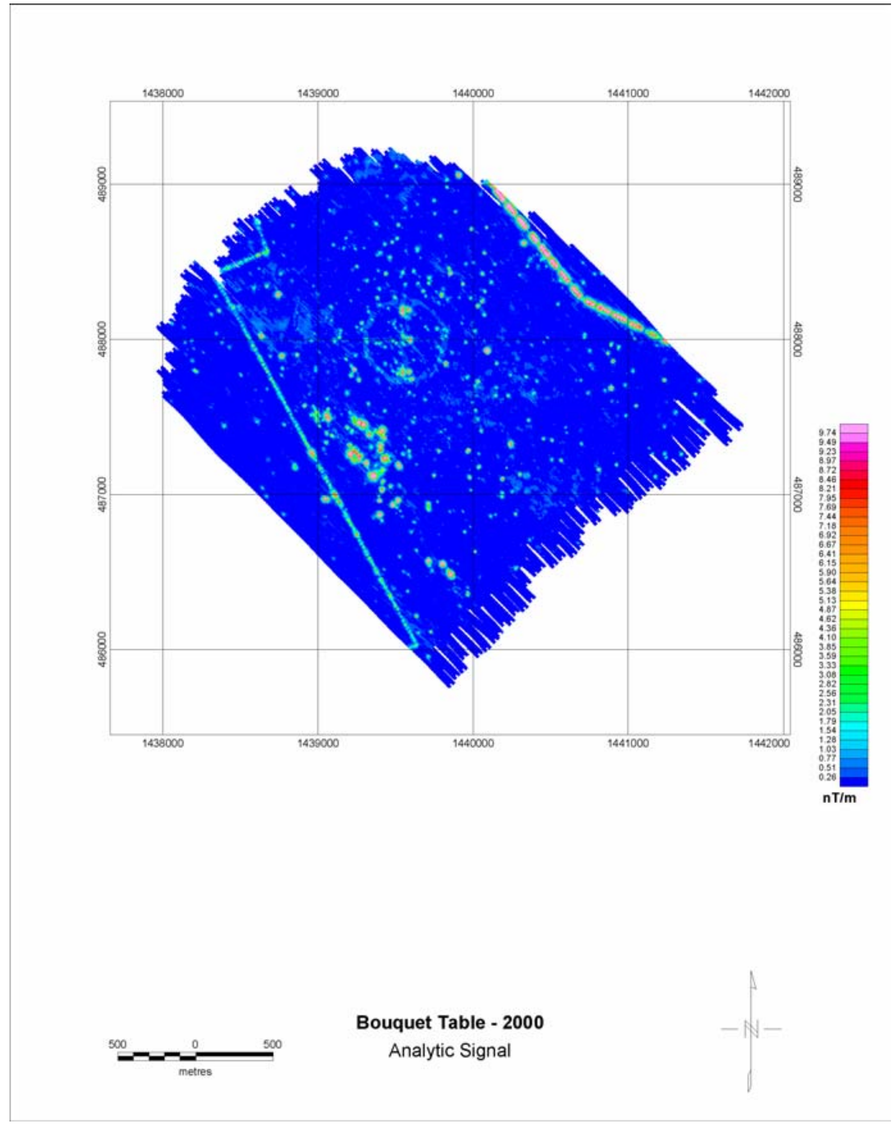

Figure 14. Analytical Signal at Bouquet Table.

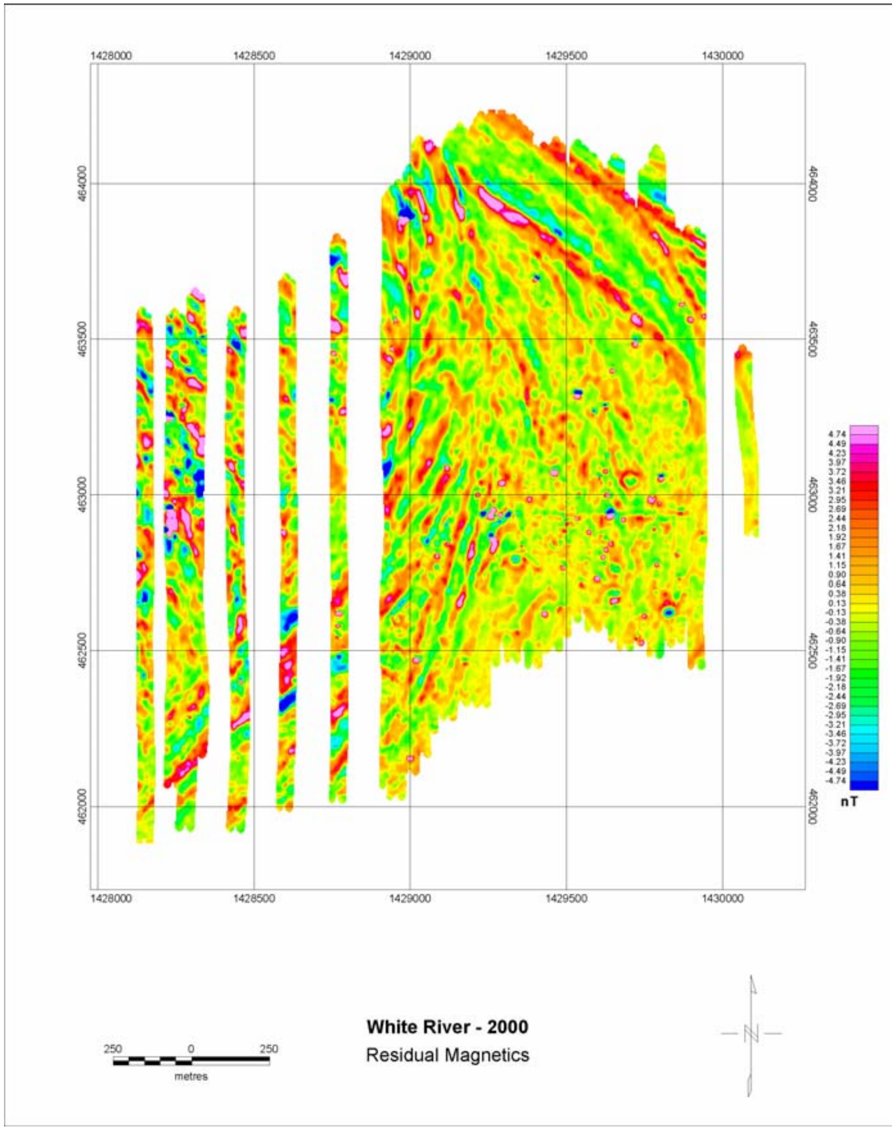

Figure 15. Residual Magnetic Field at White River.

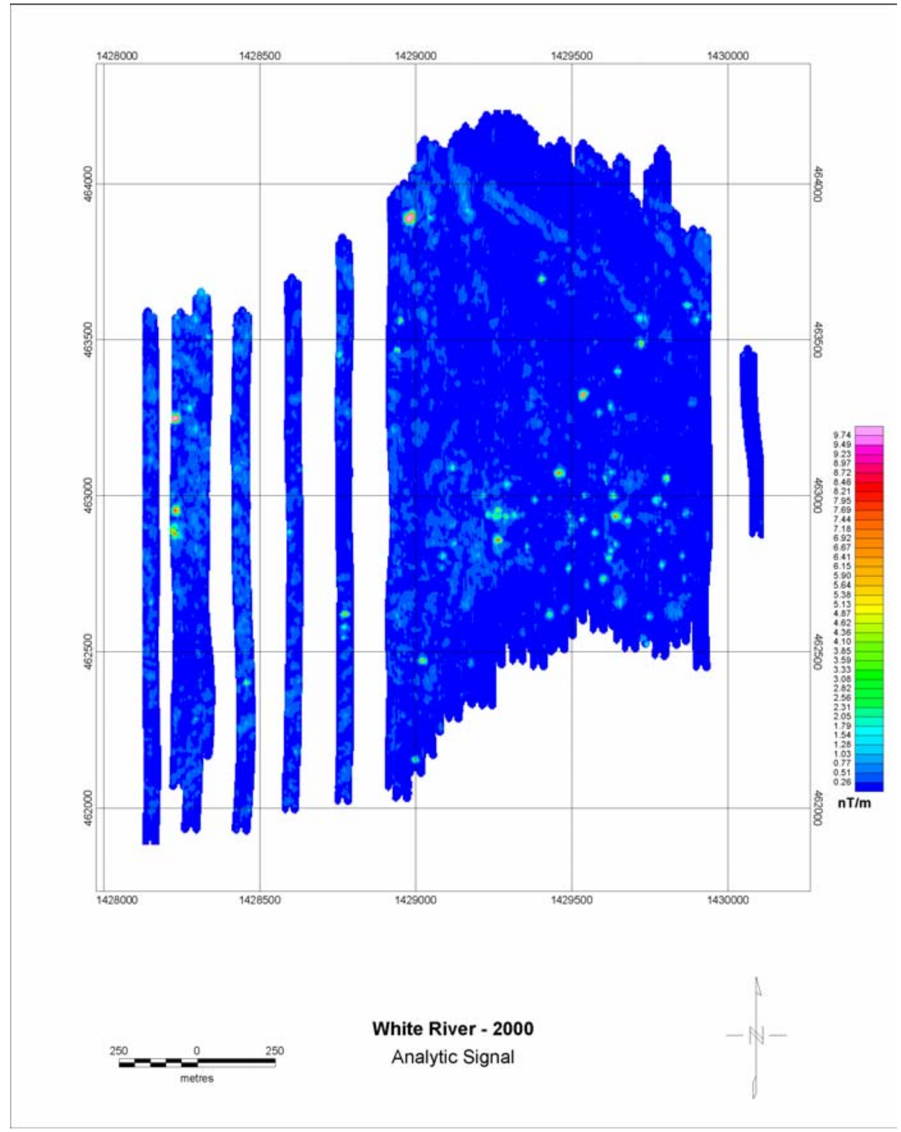

Figure 16. Analytical Signal at White River.

4.3 ROC CURVES

A receiver operating characteristic (ROC) curve was drawn for the calibration grid results (Figure 17). This is a very limited data set with limited statistical significance and does not represent a blind test, but it is the only site where sufficient ground truth exists to make these calculations. The results are somewhat unfavorably skewed by the fact that the grid was knowingly seeded with some items that were too small, too deep, or too non-ferrous for the system to detect.

Targets were chosen from the analytic signal map based on amplitude response alone. No discrimination was attempted in the anomaly selection process. Anomaly picks were sorted by decreasing amplitude and matched to the seeded items in the grid. The false positives were calculated as the cumulative false response peaks divided by the total number of anomalies. The detection probability was calculated as the cumulative true response peaks divided by the number of seeded items. The graph reaches a maximum 76% Pd and 57% false positive (FP).

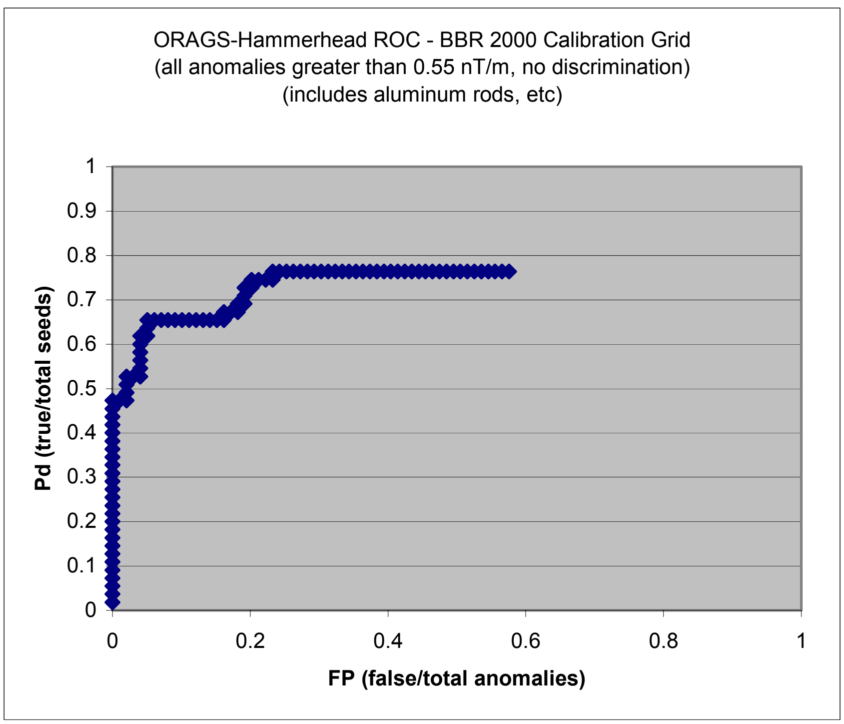

Figure 17. Results for Calibration Grid at Cuny Table.
(Using a minimum analytic signal threshold of 0.55nT/m)

The excavation results from the four remaining areas have been presented as the fraction of total digs resulting in OE versus the fraction resulting in clutter (Figure 18). The curve of this graph is quite different from the ROC curve of the calibration grid. The data were picked from the analytic signal peaks and sorted by signal strength. Only targets above a 3nT/m threshold were excavated. The flat start to the curve indicates that much of the clutter was significantly larger in amplitude than the OE items (greater than 13 nT/m). In the mid-range between 3 and 13 nT/m, the ratio of OE to

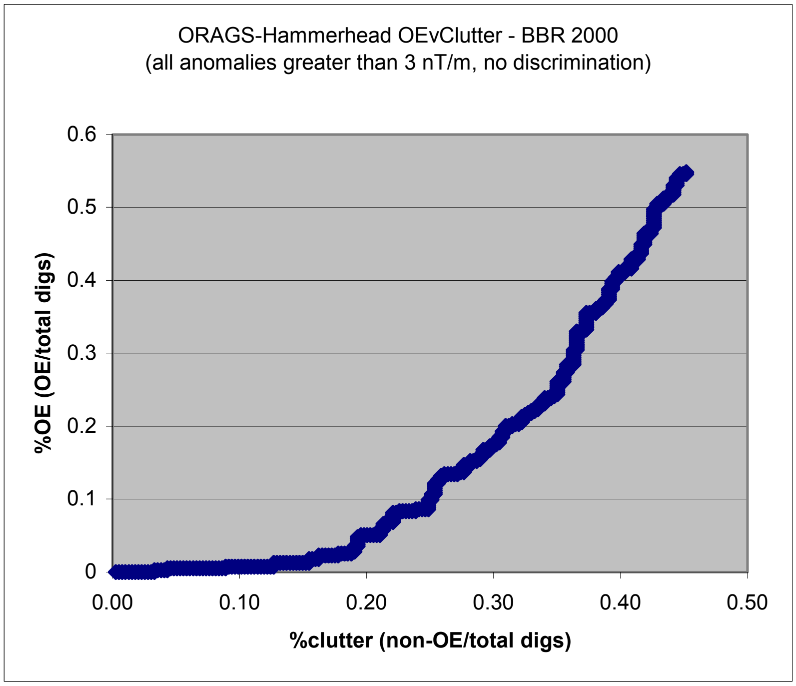

Figure 18. Ratio of OE to Clutter, Based on Excavations of Airborne Anomalies at Scenic/XU Hill, Radar Site, Bouquet Table, and White River.

(Results show that the maximum response for M38s at these sites was approximately 13 nT/m, but the minimum was not reached at the 3 nT/m excavation threshold.)

clutter was almost exactly 2:1. The fact that the curve does not reach an asymptote at the top (smallest anomalies) is probably due to the 3 nT/m excavation threshold. Further excavation of these smaller anomalies would undoubtedly result in an increasing percentage of clutter.

4.4 FALSE NEGATIVES

So far, this analysis does not include any recognition of false negative (FN) responses. The examination of the dig results from the four uncalibrated areas implies that some of the ordnance was not excavated at a threshold of 3 nT/m, but this does not imply that they were not detected in the un-excavated anomalies between 0.5 and 3 nT/m. False negatives must be determined by coincident surveys using another technology whose limitations are well-defined.

Parsons Engineering conducted such surveys over additional areas as part of an EE/CA action in the same vicinity. The cost of this action is not included in this report, but the results have been included as supplemental performance information. These additional survey blocks were flown as individual flight lines or transects primarily in areas where no ordnance was expected in order to support a "no further action" decision. Many of these lines were established to intersect with previous or planned ground surveys. Twenty-seven coincident ground surveys of 200 ft x 200 ft each were conducted using a Geometrics G-858 magnetic gradiometer. These do not include any coincident grids that were excavated prior to the airborne survey. A comparison of the ground and airborne data was conducted to substantiate the low FN expectations. A summary of the analysis is

shown in Table 5. The FN count was determined to be zero across the entire site, except for target items clearly below the system detection capabilities. In total, all 10 of the M38 targets detected by the ground-based geophysics were also detected by the airborne system, but with 309 fewer false alarms.

Table 5. Summary of Ground Versus Airborne Coincident Grid Results from Parsons EE/CA.

Area	Number of ground picks	Air picks	Air OE missed	Other missed	Follow-on
1033	34	9-M38s, 2 scrap	1-50cal	7 scrap	None
2045A	13	2 “active” soil	none	11 scrap	none
2044A	14	1 benchmark	none	13 wire and frag	none
2046A	3	none	1-20mm	2 scrap	3 new digs
4073A	10	2 wire	1-20mm	7 scrap	2 redigs, 30 adjacent
4075A	9	1 “active” soil	none	8 “active” soil	none
4077A	9	5 wires	1-20mm	3 scrap	none
4074A	30	9 wires	none	21 scrap	9 redigs
4080A	25	3 cans	none	22 scrap	none
4079A	6	2 “active” soil	none	4 “active” soil	none
4048A	3	3 scrap	none	none	3 redigs
4021	8	3 wires	1-50cal	4 scrap	6 adjacent
4069A	13	2 “active” soil	5-20mm, 3-50cal	3 scrap	none
4040A	15	2 wires	1-20mm	12 scrap	2 redigs, 9 adjacent
4120	8	1 scrap	none	7 scrap	none
4119	5	5 scrap	none	none	none
4053	11	none	6-20mm, 3-50cal	2 “active” soil	none
4011A	6	2-20mm, 3 scrap	none	3 scrap	6 redigs
6038A	6	1-50cal, 1 scrap	none	4 scrap	none
6030A	39	4 scrap	1-20mm	34 scrap, 1 “active” soil	none
6029A	1	1 “active” soil	none	none	1 redig
6027	8	none	1-20mm	7 scrap	none
6018A	32	8 wires	2-20mm	22 scrap	8 redigs
6015A	40	1-M38, 7 scrap	none	32 scrap	8 redigs
7005	22	none	5-20mm, 1-50cal	16 frag	none
7007	5	none	1-20mm, 1-50cal	3 frag	none
7030	15	none	1-20mm	14 scrap	none
TOTAL	**390**	**81**	**36**	**261**	**168**

An additional 168 anomalies were excavated or re-excavated based on this analysis. These were done to verify a selection of anomalies where the ground and airborne results were inconsistent, and as a quality assurance (QA) process for the original clean up. These additional excavations revealed two small UXO items (1-20 mm link and 1-50 caliber link).

Three coincident grids (Figure 19 through Figure 21) of airborne analytic signal with ground truth results are presented here. The first two are the only ones that contained any detectable UXO. The

third provides an example of the smaller UXO items (20 mm, 20 mm links, 50 cal, 50 cal links) that remain undetected. Figure 19 illustrates a consistent positional shift between the ORNL and Parsons coordinate systems of approximately 10 ft. In this figure, the airborne system detected all nine OE items with only two false positives. The ground survey detected the same nine OE items plus nine more pieces of scrap and false positives.

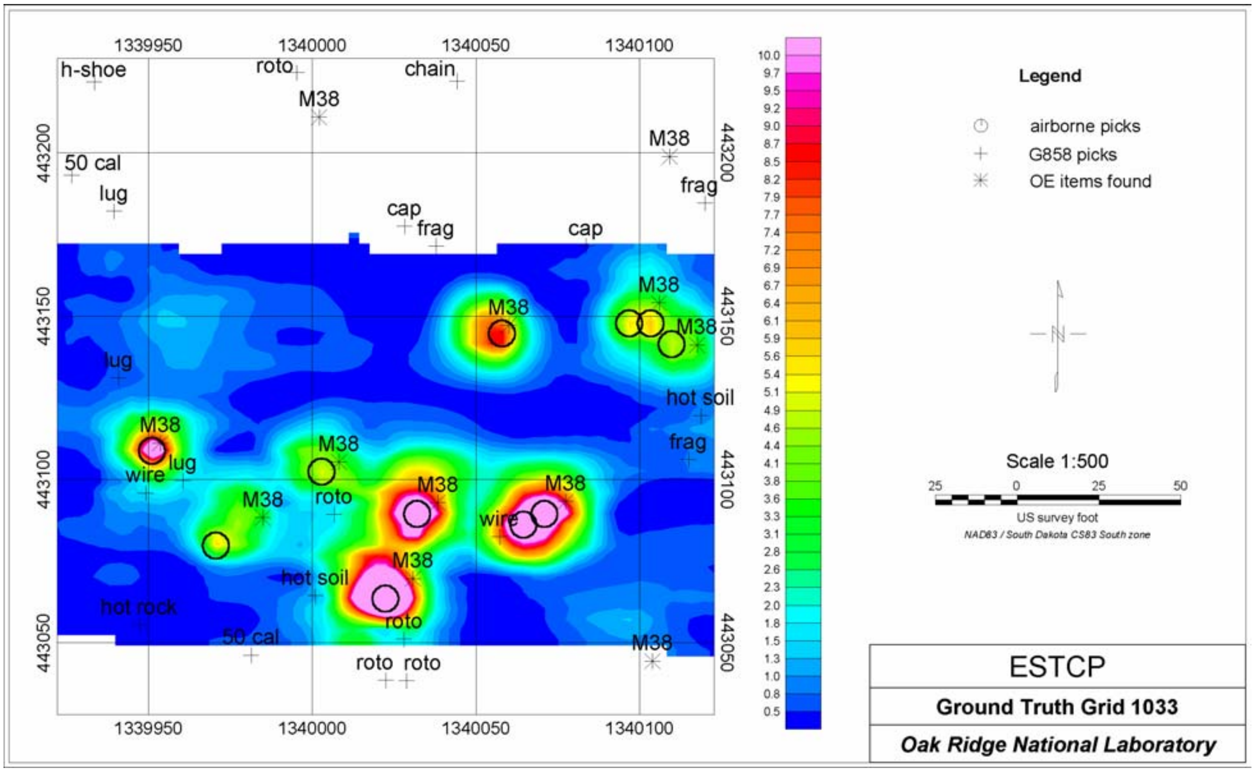

Figure 19. Ground Truth Grid 1033 Including Airborne Data.

In the second grid (Figure 20), the airborne system detected only one OE item. The coincident ground survey detected the same OE item, plus 38 pieces of scrap. In the third grid (Figure 21), the airborne system detected no anomalies while the ground survey detected one 50 mm round, two 20 mm rounds, twelve pieces of OE fragments and three false positives.

These figures support the conclusion that the airborne system is capable of detecting the M38 ordnance (but not the 50 mm or 20 mm rounds) with no incidence of false negatives and greatly reduced false positives. From this limited data set, and with the objective of detecting M38 ordnance, the ORAGS-Hammerhead system produced a probability of detection of 100% (10) with 16% (2) false positives. The ground truth over the same area produced a Pd of 100% (10) with 86% (62) false positives (not including the three smaller munitions). The use of Pd and FP numbers for this case is based on the assumption that the ground survey was perfect in its detection of all possible target items, and that no items were missed.

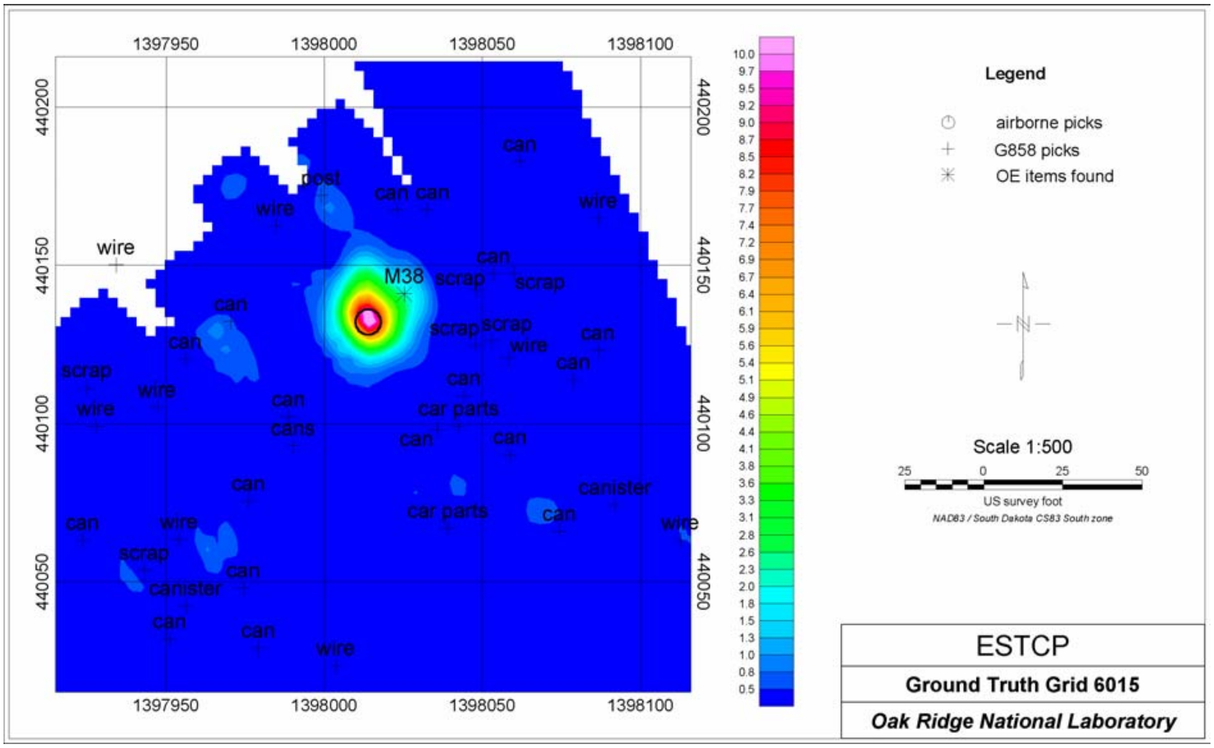

Figure 20. Ground Truth Grid 6015 Including Airborne Data.

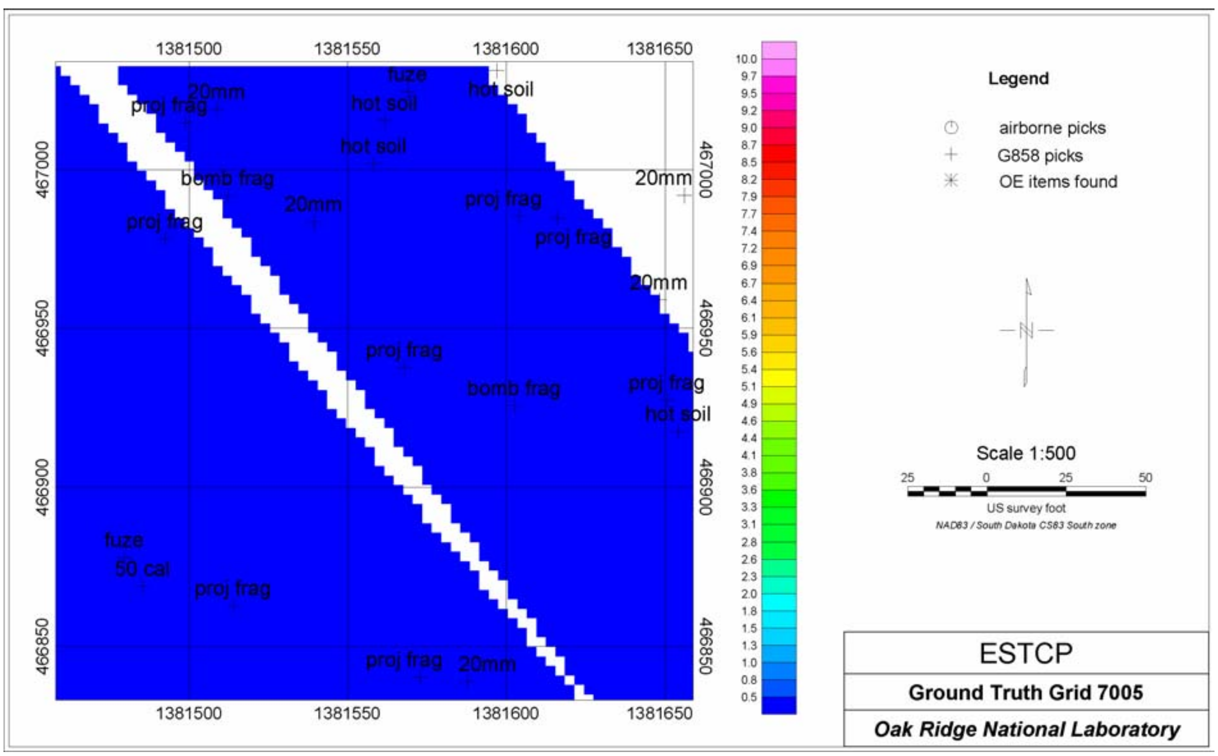

Figure 21. Ground Truth grid 7005 Including Airborne Data.

4.5 TECHNICAL CONCLUSIONS

The relevant comparison is between the ORAGS-Hammerhead airborne system used for this demonstration and the HM3™ airborne system previously used at BBR. The ORAGS-Hammerhead compares both directly and favorably in a number of ways to the less sophisticated HM3™. They can be directly compared in many areas including site coverage, detection limits, location accuracy, production rates, and costs associated with deployment and application. Both the 1999 Cost and Performance Report for the ESTCP Project entitled "Evaluation of Footprint Reduction Methodology at the Cuny Table in the Former Badlands Bombing Range" and a report from the Institute for Defense Analyses (IDA) entitled "Review of Unexploded Ordnance Detection Demonstrations at the Badlands Bombing Range – NRL Multisensor Towed Array Detection System (MTADS) and ORNL High-Sense Helicopter Mounted Magnetic Mapping System (HM3™)" provide background information used for this comparison.

In terms of site coverage, the new Hammerhead array is capable of collecting data at 1.75-m intervals using a 12-m line spacing. This compares to 3-m data collection lanes using a 9-m line spacing with the original HM3™. This represents a 2.7 times increase in acquisition capabilities (essentially, 8 versus 3 sensors per flight line). Detection limits were not reached during the 1999 BBR survey, but the inclusion of deeper and smaller test items in 2000 successfully bracketed the Hammerhead detection capabilities. A background noise level of 0.5 nT/m was established over the test grid. This represents an improvement over the previous system, mostly by virtue of the denser data sampling and the lack of interleaved flight lines.

The detection probability of the system was refined by 951 additional excavations based on the 2000 survey data. False positive responses (caused by instrument or survey noise) were reduced to 3%, while false negative responses were determined to be 0% for M38-size targets (again, based on the assumption that the ground survey was perfect in its detection capabilities). False alarms in the coincident EE/CA grids were reduced from 380 to 71 with no reduction in Pd or FN performance. The ROC curves generated by the ground follow-up results demonstrated that the ratio of ordnance to clutter in the area was approximately 2:1, and that more M38-like ordnance can be expected to be found in the 0.5 to 3 nT/m response range.

5.0 COST ASSESSMENT

5.1 DEMONSTRATION COST

The total cost of the airborne survey, including modification to the test grid at the Calibration Site, was $647,000. This represents a cost of $1,295/acre. It must be noted that this was a research project, however, and not a production survey. Several areas were flown more than once, and all areas were very small by airborne survey standards. The inefficiencies of small areas and short lines can best be demonstrated by the percentage of airtime actually spent on line. The survey of the four ESTCP grids required a total of 4 hours, 38 minutes on line, spread over 4 days of field time.

The total project required 39 hours of helicopter airtime including mobilization and demobilization over 10 days, but only 14 hours were actually spent collecting the 4.6 hours of data presented here (183 line km of flying at 20 m/s). The remainder of the time was spent on mob/demob, on ferry flights to and from the site, flights for refueling, on various calibration and experimental runs, turn-arounds at the end of lines, and on re-flights due to inadequate data quality. In addition, costs associated with the modification to and installation of the seeded items at the Calibration Site are included within the total cost for the project. The actual project demonstration costs are presented in Table 6.

Table 6. Actual Total Demonstration Project Cost in FY 2000.

Task	Labor	Overhead ($)	Subcontract ($)	Total ($)
Subcontract placement	900	600		1,500
Magnetic survey mission planning	3,300	2,200		5,500
Airborne magnetic data acquisition	23,400	17,600	96,000	137,000
Airborne magnetic data acquisition oversight	5,200	4,000		9,200
Magnetic data postprocessing	12,600	7,700	41,000	61,300
Magnetic data analysis	22,600	13,600	7,200	43,400
Data integration and management	9,400	7,000	6,100	22,500
Preparation of products	3,900	2,600		6,500
Final report	9,600	6,600		16,200
Travel	7,300	600		7,900
Project management, computer support, and materials	16,500	12,300		28,800
Federal acquisition cost (DOE) (3% of total)	3,400	2,300	4,500	10,200
Subtotal	**118,100**	**77,100**	**154,800**	**350,000**
USAESCH direct funding contribution	27,200	20,400		47,600
Parsons Engineering Sciences EE/CA support	59,100	44,600		103,700
Federal acquisition cost (DOE) (3% of total)	2,100	1,600		3,700
Parsons validation/intrusive investigations			75,000	75,000
Subtotal	**88,400**	**66,600**	**75,000**	**230,000**
ORNL in-kind contribution	67,000	N/A		67,000
TOTAL				**647,000**

The area surveyed during the demonstration that represents the closest to full production rates would be Bouquet Table. It was completed in a single flight of approximately 1.2 hours with one additional flight of 0.5 hours for reflights. Projections for future sites based on the work here and previous projects indicate daily coverage rates of 200 acres/day at a cost of $200/acre.

5.2 TYPICAL AIRBORNE SURVEY COSTS

Table 7 represents costs associated with the airborne-based technology in a "real-world" implementation when operated at the scale of the demonstration. The scale of the demonstration for this cost profile is a 500-acre site, slightly larger than the original area surveyed during the actual demonstration. All costs represented in the table are costs that would be incurred only for a "production" demonstration at a "real-world" site, and do not reflect any costs associated with the demonstration of an innovative technology. It is important to note that costs associated with excavation for ground-truthing and verification *are not* included in this cost profile.

Table 7. Cost Estimate for UXO Technology Demonstration in FY 2000 for a Sample 500-Acre Survey.

Cost Category	Subcategory	Costs ($)
	FIXED COSTS	
1. Capital costs	Mobilization/demobilization	42,900
	Planning/Preparation/Health and Safety Plan (Mission Plan)	10,500
	Equipment	24,900
	Management support	8,500
	Subtotal	**86,800**
	VARIABLE COSTS	
2. Operation and maintenance	Operator labor	13,600
	Labor for data processing, analysis, and interpretation	28,600
	Instrument rental or lease	5,500
	Helicopter support services	22,100
	Travel and miscellaneous materials	4,500
	Reporting	5,500
	Subtotal	**79,800**
3. Other technology-specific costs	Excavation for ground-truthing and verification	Not included
	Establishing calibration site	Not included
	Subtotal	**0**
4. Miscellaneous costs	DOE federal acquisition cost (FAC)	5,000
	TOTAL COSTS	
	Total technology cost	**$171,600**
	Throughput achievable (acres per hour)	**35**
	Unit cost per acre	**$343**

Also of note, no one-time, demonstration-related costs associated with survey optimization, detailed Calibration Site analysis, nonroutine analysis, or excessive reflights over the survey areas to evaluate or refine the demonstration are included in the costs outlined in the table. Although these costs are not included, the cost/acre is still quite high due to the small survey size (500 acres). Reasonable efficiencies (better than ground survey costs) are not achieved until the survey size is approximately 1,000 acres.

Often, specific survey sites and parameters are unknown or ill-defined during the early stages of project planning when consideration is being given to which geophysical technology implementation is most applicable. With this in mind, a typical set of cost estimates was developed that could be used for project planning purposes. These cost estimates were based on early cost models for conducting similar airborne magnetometer surveys, as well as incorporating lessons learned and final project costs from similar past projects at Canadian Forces Base Borden, Jüterbog Tank Training Range, and Edwards Air Force Base. While initial calculations of survey costs included a variable associated with geographic locale, it was determined that this variable was actually a constant (approximately) due to the offsetting of ORNL mobilization/demobilization costs and the ferry time for a regional helicopter provider to mobilize/demobilize from the survey sites. In addition, the survey cost estimate models assume surveys are conducted over relatively large contiguous areas. Surveys conducted over areas less than 500 acres are not reflected in these cost models and require a different estimation structure. Costs for reacquisition and intrusive sampling are also *not* included in the models.

These generic cost estimates include the following factors:

- Project management
- Mobilization/demobilization of the applicable airborne technology
- Data acquisition (including equipment and helicopter costs)
- Data processing, analysis, and interpretation
- Reporting
- Travel, materials, and miscellaneous expenses
- Federal acquisition cost (3% congressionally-mandated administrative fee to DOE)
- 5% project contingency to account for weather, etc.

Figure 22 and Figure 23 depict the cost estimate model for airborne magnetometer survey cost as a function of survey size in acres and the cost estimate model for airborne magnetometer survey cost per acre as a function of survey size in acres, respectively.

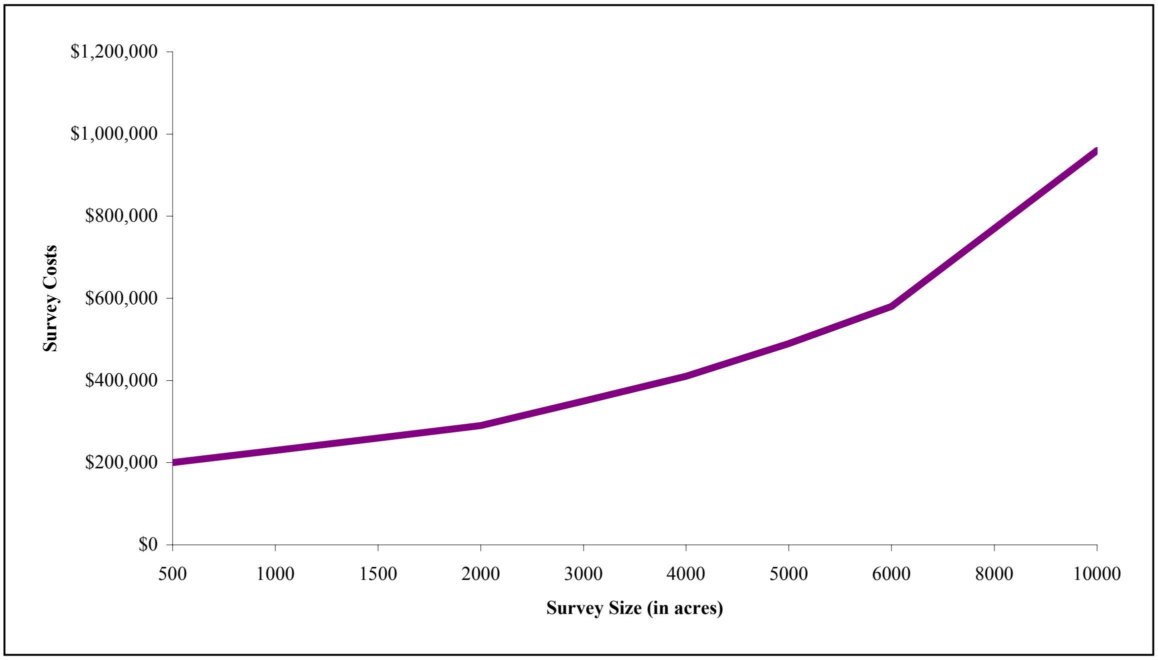

Figure 22. Airborne Magnetometer Survey Cost.

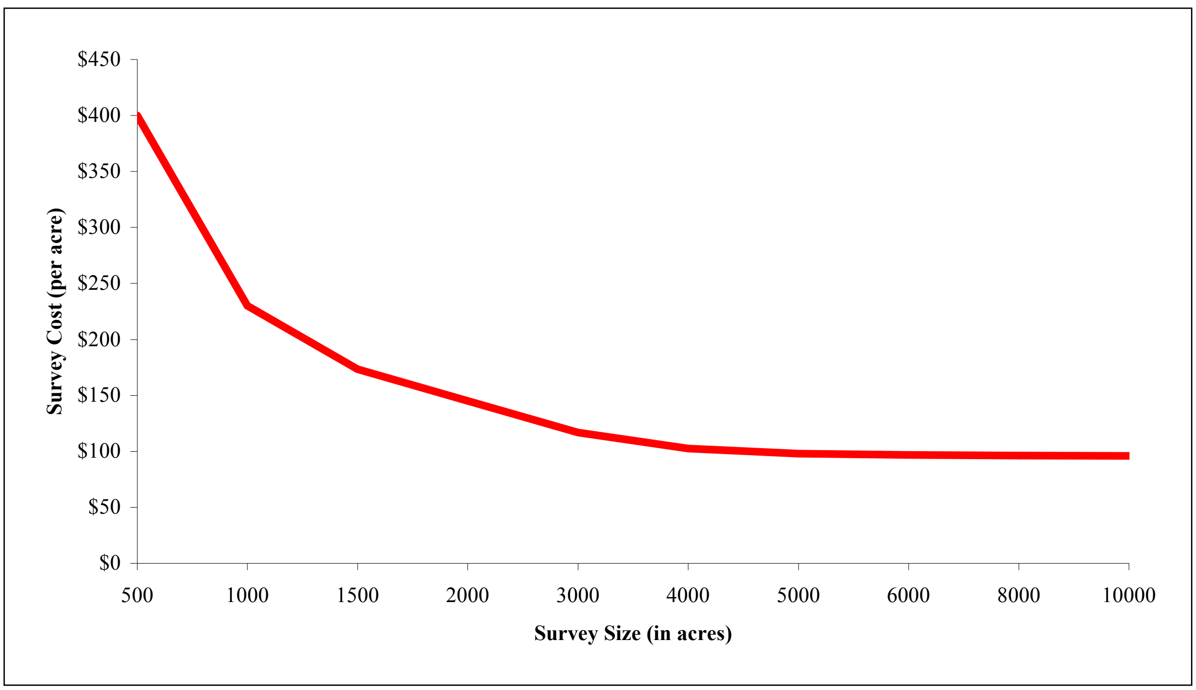

Figure 23. Airborne Magnetometer Survey Cost per Acre.

5.3 COST ANALYSIS

The major cost driver for an airborne survey system is the cost of helicopter airtime. In terms of tasks, this constitutes most of the data acquisition costs–the single largest cost item.

Data processing and analysis functions made up the bulk of the remaining costs. The costs associated with development of robust processing algorithms were a major factor in this particular survey. This is expected to diminish with each project as solutions to common scenarios are found. Mobilization is also a major task in terms of cost. Generally, this is a function of distance from the home base for the helicopter and equipment. Peripheral costs associated with this demonstration and validation project, such as ground truth and excavations, *were not* considered in this part of the cost analysis.

The sensitivity of the overall cost to these drivers can be modeled under several different scenarios. Helicopter time on site is a factor of several variables. The first is the number and dimensions of the survey blocks. The greatest amount of non-survey time is spent in turns at the end of each line in preparation and alignment for the next line. Fewer and longer survey lines are therefore more efficient than numerous shorter ones.

The areas surveyed under this project demonstrate the efficiency of several different scenarios. The test grid is an example of a particularly small survey area (2.5 acres). On the other end of the scale, Stronghold Table required only slightly more time to cover 42 acres–more than an order of magnitude increase in efficiency. The bombing targets (Cuny Table Bombing Target and Aerial Gunnery Target) required close to 6 hours each and covered 92 acres each. The relative efficiency of each of these scenarios is summarized in Table 8. The results show a nearly linear relationship between length of the survey line and the survey efficiency. These results will reach a plateau at a theoretical 185 acres/hour, which represents the maximum speed of the aircraft with zero time for turns.

Table 8. Airborne Survey Efficiency Parameters. (includes time on survey grid only)

Name	Coverage (in acres)	Airtime (in hours)	Efficiency (in acres/hour)	Line length (in km)
Scenic/XU Hill Bombing Target	178	1.2	148	5.0
Radar Bombing Target	98	0.8	123	2.7
Bouquet Table Bombing Target	166	1.9	87	2.5
White River Bombing Target	55	0.8	69	2.0
Calibration Site	2.5	1.0	2.5	0.2

Lines longer than approximately 8-10 km do not gain additional efficiencies. One mitigating factor to this limit is a pilot performance issue. Longer lines typically require more frequent reflights since it is more difficult to maintain precision flying over such long lines. In practice, a maximum line length of 5 km is advised.

The other major cost drivers were data processing and mobilization/demobilization. Processing and mobilization costs are generally linear with project size and transportation distance, respectively. Processing costs and data deliverable times will decrease with experience at multiple sites. Continued and consistent use of a static technology could lead to overnight delivery times. Mobilization costs are unlikely to decrease with time. The use of a local helicopter and pilot may offer decreased mobilization costs, but risks significantly increased acquisition costs if the mechanic in charge of installation is unfamiliar with the equipment, or if the pilot is uncomfortable with the level of precision flying required.

5.4 COST COMPARISONS

This section compares costs of several radically different survey technologies. These include man-portable, a ground towed-array (MTADS), the HM3 airborne array, and the Hammerhead airborne array.

Based on several sources of information regarding the deployment of ground-based towed array systems on a UXO contaminated site, four scenarios are presented for the purpose of comparing airborne surveys to ground-based surveys. These sources of information are generally informal and include discussions with industry and USAESCH staff experienced in the application of ground-based towed array surveying equipment and projects.

The scenarios described include sites of 500, 1,000, 1,500 and 2,000 acres of geographic extent, with respective costs of $400, $225, $175 and $150 per acre for the airborne survey portion of the cost comparison. These per acre values were taken directly from Figure 23. These comparisons between airborne and ground based man-portable magnetometer surveys are summarized in Table 9. Neither the airborne nor the ground-based survey costs include the cost of excavation.

Table 9. Cost Savings Between Airborne and Man-Portable Survey Costs.

Area (acres)	Airborne Cost ($/acre)	Airborne Total ($)	Ground Cost ($/acre)	Ground Total ($)	Savings ($)
500	400	200,000	1,000	500,000	300,000
1000	225	225,000	1,000	1,000,000	775,000
1500	175	263,000	1,000	1,500,000	1,237,000
2000	150	300,000	1,000	2,000,000	1,700,000

While both simplistic and generalized in nature, it is readily apparent that when the area of concern for potential UXO contamination becomes large, the costs for performing a ground-based man-portable survey become large as well when compared to the application of the airborne systems.

A more reasonable cost comparison for an airborne array is against a ground-based towed array of magnetometers similar to MTADS. This comparison was chosen for the following reasons.

- MTADS was deployed at the same sites at BBR as the airborne technology (as reflected in the IDA report), enabling an easy comparison for broad-area search technology.

- The HM3™ was deployed at the same sites at BBR in the previous ESTCP project.
- USAESCH performed an assessment of costs associated with contractors that employ ground-based towed arrays for geophysical surveying at UXO sites.
- The extent of coverage possible with an airborne system renders comparisons to handheld man-portable systems somewhat inappropriate.

Beginning with the cost comparison outlined in the IDA report, the following was extracted from the IDA report: "For this demonstration, the MTADS total cost was $377,296. If the excavation costs of $169,096 and the reporting costs of $24,000 are removed, the MTADS costs for the deployment, survey, and analysis parts of this demonstration were $184,200. Note that this does not separate out the costs of the electromagnetic induction (EMI) work. The MTADS surveyed a total of more than 150 acres for a cost of $1,222 per acre. For the HM3™, the total costs of this demonstration were $220,000 to survey 287 acres, for a cost of $766 per acre." According to the IDA report conclusions, "Cost estimates prepared by the performers indicate that the per acre cost of the MTADS is about 2–3 times higher that those of the HM3™. These figures are very rough estimates and may not accurately reflect the cost differences seen in operational surveys."

USAESCH performed an assessment of contractor costs associated with ground-based towed magnetometer arrays (similar to or the same as MTADS). Table 10 reflects the costs for a 287-acre survey, and includes all costs similar to the airborne survey illustrated in Table 7. As determined in the IDA report, the MTADS cost/acre is roughly twice that of the airborne system.

Table 10. Representative Cost for UXO Ground-Based Technology at Demonstration Scale in FY 1999.

Cost Category	Subcategory	Costs ($)
FIXED COSTS		
1. Capital costs	Mobilization/demobilization	6,614
	Planning/Preparation/Health and Safety Plan (Mission Plan)	1,746
	Equipment	Included in survey cost
	Management support	Included in survey cost
		Subtotal 8,360
VARIABLE COSTS		
2. Operation and maintenance	Ground-based survey	129,650
	Labor for data processing, analysis, and interpretation	37,800
	Instrument rental or lease	Included in survey cost
	Travel and miscellaneous materials	26,060
	Reporting	4,230
		Subtotal 197,740
3. Other technology-specific costs	Excavation for ground-truthing and verification	Not included
	Geophysical prove-out	5,616
		Subtotal 5,616
4. Miscellaneous costs	None noted	0
TOTAL COSTS		
	Total technology cost	**$211,716**
	Throughput achievable (acres per hour)	**3**
	Unit cost per acre	**$735**

Even closer to the Hammerhead array are the costs associated with the previous HM3 ESTCP demonstration. The cost factors involved in the HM3 and Hammerhead surveys are virtually identical. Apart from the learning curve associated with field experience, only the rate of survey coverage has changed significantly between the two technologies. The HM3 survey coverage was based on 9 m flight line spacing, whereas the Hammerhead is based on 14 m flight lines. This produces a 1.5x increase in productivity. Coupled with the increased data density (from 3 to 1.75 m between data traces), this effectively produces a 2.7x increase in survey capacity, although the increase in data density does not translate directly into a cost savings over the HM3. Assuming that the capital costs in Table 6 remain the same for both Hammerhead and HM3 technologies, the operational costs will benefit from the 1.5x productivity increase. The Hammerhead array thereby sees a total cost reduction of 25% over a comparable HM3 survey—plus the benefit of the additional data density and quality.

5.5 COST CONCLUSIONS

As demonstrated above, comparing costs of fundamentally different technology approaches is both difficult and inconclusive. The previously discussed cost comparison provide a range of answers to the same question, namely, what are the costs of deploying each technology over the same size area under the same conditions?

For consideration of DoD-wide application of the airborne technology, a number of factors must be considered when evaluating the appropriateness of the airborne technology and potential for substantial cost savings. While initially impressive, it is not possible to simply apply these types of cost savings across the entire DoD UXO program. Sites must be of sufficient geographic extent to warrant a deployment given the high costs associated with mobilization and demobilization. In addition, terrain, geology, and vegetation must also be considered for such a deployment. Variable terrain and/or the presence of tall vegetation can greatly limit or prevent the use of the airborne technology for the UXO objectives of interest. Finally, the UXO target objectives must be of sufficient size (2.25-in rockets or larger) to fall within the detection limits of the airborne system to make such a deployment feasible.

6.0 IMPLEMENTATION ISSUES

6.1 COST OBSERVATIONS

Costs were largely within the original estimates. Data acquisition, processing. and analysis tasks consumed approximately 60% of the funding. The presence of Parsons Engineering Science at the site reduced the cost of ground follow-up and excavation. This project was able to leverage mobilization costs to reduce the total expenditures. The project leveraged costs from the EE/CA work being conducted on behalf of Parsons Engineering in addition to testing a prototype airborne electromagnetic system.

The site was geologically ideal, but logistically difficult. Overnight staging was done from the Rapid City Regional Airport, while day time refueling of the helicopter was done at Cuny Table by truck. In spite of this, most of the survey blocks were still tens of miles away from the base of operations. With a one-way flight time of nearly 30 minutes, this reduced the available onsite survey time to approximately 1.5 hours per flight. The ferry time between the airport and the survey site therefore represented a significant portion of the airtime.

Additional cost savings may be possible in the data processing and analysis tasks. As noted earlier, a considerable amount of time was devoted to developing or refining the processing methodology. The continued and consistent use of a static technology should reduce most of the processing procedures to a semiautomated technique. Under these conditions, rapid delivery of survey results should be possible. This really applies only to a production-oriented system. In a research platform, continued modifications to the system or new improvements to the processing methods will largely negate this benefit.

6.2 PERFORMANCE OBSERVATIONS

The primary performance objectives were greatly exceeded by this demonstration. Practical survey heights were lower than expected and the additional bandwidth in data recording allowed for much higher resolution of the seeded targets. The test grid was established with the objective of bracketing the detection capabilities of the system by placing smaller and deeper items than the previous demonstration.

The objectives of this project were to demonstrate detection of ferrous targets, whether ordnance or non-ordnance. No attempt was made at classification, which made ground follow-up difficult to analyze with traditional UXO techniques (P_d and FP). False positives (anomalies with no associated ferrous item) were determined to be 3%, but this is a measure of system and survey noise and not to discrimination (as is usually the case with UXO surveys). Ground follow-up demonstrated that there were no false negative responses for M38-size targets.

6.3 SCALE-UP

Scale-up of operations could be conducted from either of two scenarios. The first scenario uses the current technology as is, with only minor modifications. The second scenario uses more comprehensive modifications to improve efficiency and resolution.

The current technology requires minor hardware and firmware modifications to improve aircraft and data positioning. Suitable training of geophysical personnel to handle the data processing will also be required, once the methodology has been refined to a more automated process. Given the current market conditions, equipment availability should not be an issue. A single operating system should be sufficient to handle all of the available work for the foreseeable future. At present, qualified personnel represents the most significant obstacle.

The second option incorporates more comprehensive modifications to the system in an effort to improve efficiency and data quality. The innermost sensors exhibit significantly more noise than the rest of the array and should be moved to a quieter spot of the helicopter. A vertical gradient system may also provide advantages in terms of noise cancellation and sensitivity to small targets. As with the first option, a single system should be sufficient to handle current market demand, and the most significant obstacle is the shortage of qualified personnel. In addition, new processing techniques would have to be tested to handle the new data configuration.

6.4 OTHER SIGNIFICANT OBSERVATIONS

As mentioned previously, major factors in implementing or deploying the airborne system are topography and vegetation. Steep topographic variations make it difficult to achieve uniform altitude across the survey area. Most topographic features will be coherent between lines, which makes them easy to identify and will not be confused with ordnance signatures. The impact on data quality is that the average altitude will increase, making it more difficult to detect smaller objects.

Vegetation has a similar effect on data quality in that it necessitates an increase in survey altitude. Isolated pockets of vegetation or single trees can be handled in two ways. The first is to fly over them and create a small pocket of lower resolution data. The second is to fly around them and create a minor gap in data coverage. Continuous stretches of vegetation or forest should be avoided.

Geologic influence is another factor impacting the technology implementation. The difficulty of detecting ordnance in highly magnetic environments is well-documented and impacts the airborne system as it would a ground system. The only recognized solution to this problem would be to develop an airborne electromagnetic system.

6.5 LESSONS LEARNED

The primary benefit of this technology is in rapid reconnaissance of large open areas, commonly referred to as footprint reduction. Cost analysis shows that costs per acre decrease significantly with the size of the project whereas ground surveys tend to have a fixed cost per acre. It would therefore be prudent to survey as large an area as possible with each mobilization, even if all the data are not processed immediately.

6.6 END-USER ISSUES

End users have been included in the project as often as possible. The USAESCH innovative technology director is the project principal investigator. The Oglala Sioux (landowners) have been included in the project conception and preparation, and Parsons Engineering Science has conducted the ground truth in parallel to their own EE/CA activities. Parsons has also expressed an interest in having one or more of their geophysicists trained to handle airborne magnetic data. All of these parties have been supportive and encouraged by the survey results to date. In particular, the explosive ordnance disposal (EOD) technicians responsible for the excavations have expressed their admiration for the positioning accuracy of the results.

6.7 APPROACHES TO REGULATORY COMPLIANCE AND ACCEPTANCE

It is important to recognize the different aspects associated with the regulatory involvement in the technology and the application of the technology to a UXO-contaminated site. With regard to the application of the technology, there are issues associated with regulatory drivers and involvement of both regulatory entities and other stakeholders that are relevant.

Although no specific regulatory drivers exist at this time for UXO-contaminated land, UXO clearance is generally conducted under CERCLA procedures. A draft EPA policy is currently under review as attempts to establish a “Range Rule” were abandoned. Despite the lack of specific regulatory drivers, many DoD sites and installations are aggressively pursuing innovative technologies to address issues associated with ordnance and ordnance-related artifacts (e.g., burial sites) that resulted from weapons testing and/or training activities. These issues include footprint reduction and site characterization, areas of particular focus for this technology demonstration. In many cases, the prevailing concerns at these sites become a focus for the application of innovative technologies in advance of anticipated future regulatory drivers and mandates.

There are several types of sites where UXO contamination is an issue. These include closed, transferred, and transferring (CTT) ranges, such as FUDS and BRAC sites, as well as sites on active and inactive ranges that are not scheduled for closure. Where sites are designated for civilian reuse, it is important that the UXO be removed to the extent possible and that proper safeguards be established where there is any possibility that live ordnance might still be in place. It is also important that a permanent record be maintained to document all measurements that are made to support clearance activities. Advanced technology, such as the airborne system, is expected to contribute to the performance of these activities in terms of effectiveness as well as cost.

With regard to the technology itself, the only regulatory agency involved in the implementation of this technology is the FAA. Since the boom mounting structure is bolted directly to the hard points of the aircraft, this installation becomes a modification to the airframe that requires FAA approval. These approvals were obtained in the form of a STC. This certificate was obtained by the aeronautics engineer at the time of manufacture and permits the installation of this equipment in any standard Bell B206L Long Ranger aircraft.

This page left blank intentionally.

7.0 REFERENCES

1. Bell, D. T., Doll, W. E., Gamey, T. J., Millhouse, D. S.; July 2002, Cost and Performance Report for the 1999 ESTCP Project Entitled "Evaluation of Footprint Reduction Methodology at the Cuny Table in the Former Badlands Bombing Range."

2. Doll, W. E., Gamey, T. J., Bell, D. T., Millhouse, D. S.; July 2000, Evaluation of Footprint Reduction Methodology at the Cuny Table in the Former Badlands Bombing Range: Final Project Report.

3. McDonald, J. R., Nelson, H. H., Robertson, R., Jeffries, R. A.; September 1999, MTADS Unexploded Ordnance Operations at the Badlands Bombing Range: Final Project Report.

4. Bell, D. T., Doll, W. E., Millhouse, D. S.; July 1999; Remote Sensing Project at the Cuny Table Former Badlands Bombing Range: Proposal to the Environmental Security Technology Certification Program.

5. Andrews, A. M., Rosen, E., Chappell, I.; December 2001; Institute for Defense Analyses' Review of Unexploded Ordnance Detection Demonstrations at The Badlands Bombing Range - NRL Multisensor Towed Array Detection System (MTADS) and ORNL High-Sense Helicopter Mounted Magnetic Mapping System (HM3), IDA Document Number D-2615.

6. Bell, D. T., Doll, W. E., Gamey, T. J.; August 2000; Airborne Geophysical Survey of Selected Department of Defense Sites in the Continental United States for the U. S. Army Engineering and Support Center, Huntsville, in Support of the Environmental Security Technology Certification Program (ESTCP): White Paper.

This page left blank intentionally.

APPENDIX A

POINTS OF CONTACT

Point of Contact	Organization Name and Address	Phone/Fax/E-mail	Role in Project
D. Scott Millhouse	U.S. Army Engineering and Support Center, Huntsville 4820 University Square Huntsville, AL	(256) 895-1607 (256) 895-1602 Scott.D.Millhouse@HND01.Usace.army.mil	USAESCH Innovative Technology Manager and Principal Investigator
David T. Bell	Oak Ridge National Laboratory P.O. Box 2008 Oak Ridge, TN 37831-6038	(865) 574-2855 (865) 5747420 belldt@ornl.gov	ORNL Project Oversight
William E. Doll	Oak Ridge National Laboratory P.O. Box 2008 Oak Ridge, TN 37831-6038	(865) 576-9930 (865) 574-7420 dollwe@ornl.gov	Geophysicist; data processing, analysis, and interpretation
T. Jeffrey Gamey	Oak Ridge National Laboratory P.O. Box 2008 Oak Ridge, TN 37831-6038	(865) 574-6316 (865) 574-7420 gameytj@ornl.gov	Geophysicist; data processing, analysis, and interpretation

ESTCP Program Office

901 North Stuart Street
Suite 303
Arlington, Virginia 22203

(703) 696-2117 (Phone)
(703) 696-2114 (Fax)

e-mail: estcp@estcp.org
www.estcp.org